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A PRESCRIBED BURN DECISION SUPPORT SYSTEM FOR THE KANSAS FLINT HILLS REGION

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1. INTRODUCTION

During March and April each year, ranchers and farmers in the Kansas Flint Hills region burn two to three million acres of rangeland. These annual burns have been a longstanding land management practice in the region (Fig. 1). However, smoke generated by these burns can impact downwind cities (Fig. 2), and the air quality impacts on the public from this smoke have gained more attention in recent years. The smoke and precursor emissions can cause negative health effects, and as the National Ambient Air Quality Standards (NAAQS) for particulate matter and ozone become more stringent, there is added concern that these smoke impacts could contribute to exceedances of the NAAQS.

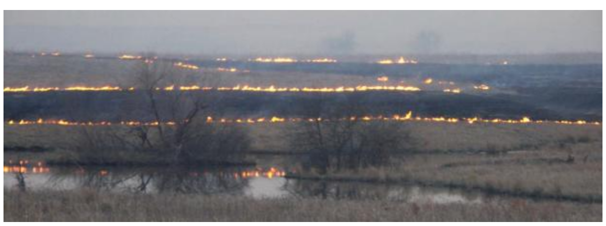

Fig. 1. A rangeland burn in the Kansas Flint Hills. From KDHE (2010).

To mitigate these impacts, the Kansas Department of Health and Environment (KDHE) developed and adopted the Kansas Flint Hills Smoke Management Plan (Kansas Department of Health and Environment, 2010). This smoke management plan attempts to balance the need for prescribed fire with the need for clean air in downwind communities. An important component of this plan is providing stakeholders with tools to help them make burn/no-burn decisions based on whether meteorological conditions are good for minimizing adverse air quality impacts from planned fires.

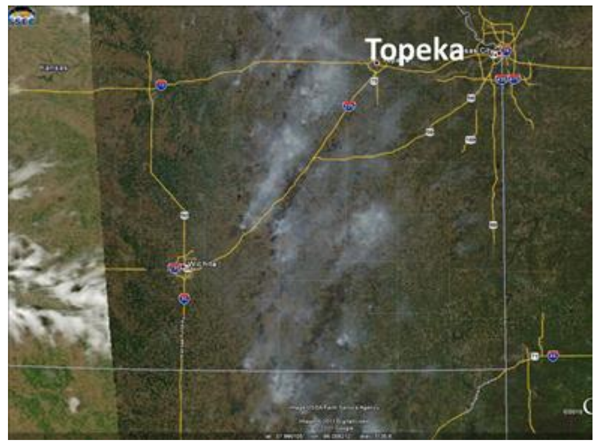

Fig. 2. MODIS satellite image of smoke from fires in the Flint Hills region being transported toward Topeka, Kansas, on April 12, 2011.

To help satisfy this need, Sonoma Technology, Inc., developed a prescribed burn decision support system (DSS) for KDHE that provides land managers with daily smoke forecasts and localized guidance on when and where to burn to avoid adverse air quality impacts on downwind cities. An intuitive web interface provides access to smoke predictions and localized guidance to support current and next day burn/no-burn decisions and help reduce downwind air quality impacts from prescribed fires. This guidance consists of model-based products, supplemented by a forecast discussion of regional weather conditions and a five-day extended outlook prepared by air quality meteorologists.

The Flint Hills prescribed burn DSS was operational during the 2011 and 2012 burn seasons. This paper describes the DSS and its forecasting tools, and discusses how model forecasts, augmented by air quality meteorologists, add value in predicting adverse air quality impacts in Kansas.

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2. DECISION SUPPORT SYSTEM TOOLS

2.1 Website

The focal point of this DSS is an easy-to-use web interface, which can be accessed through the KDHE Flint Hills smoke management website at http://www.ksfire.org. The DSS website provides land managers with access to current and next-day county-level burn guidance based on modeling output, forecast discussions, and extended outlooks from air quality meteorologists. Subsequent sections discuss the guidance tools available through the website that land managers can use to reduce the air quality impact of planned burns. It should be noted that compliance with the guidance provided through this website is strictly voluntary. The guidance is intended to guide decisions only on the basis of air quality, and is not intended to guide burn safety decisions.

2.2 Cumulative Fire Impact Maps

The cumulative fire impact maps (Fig. 3) provide land managers with a tool to assess the potential for smoke from burns in a given county or sub-region that may adversely impact air quality in Wichita, Topeka, and/or Kansas City. This model-based forecast tool assumes a worst-case but frequently observed scenario in which multiple fires occur simultaneously, and uses emission rates from burn days in prior years when air quality in downwind cities exceeded the NAAQS. Each region in these cumulative fire impact maps is color-coded to indicate the predicted level of contribution to air pollution in the urban areas. For example, a red county indicates that if prescribed burns took place in that county, smoke and precursor emissions from those burns would make a large contribution to the total air pollution in one or more of the urban areas. With the red, yellow, and green color coding, land managers can quickly assess where burning is most likely to adversely affect urban air quality. These cumulative impact maps provide the context to assess impacts of individual burns.

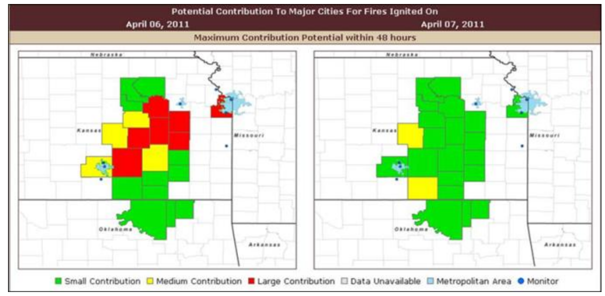


Fig. 3. Cumulative impact forecast maps generated for April 6 (left) and April 7, 2011 (right). The red, yellow, and green color-coding indicates whether fires in a county are expected to make a large, medium, or small contribution to smoke in urban areas.

2.3 Individual Fire Impact Maps

Land managers can use the individual fire impact maps (Fig. 4) to assess potential smoke impacts based on the expected size of their planned burn, and the fuel density condition of their land. Users select from a pre-determined set of fire locations (by county or sub-region), burn sizes (less than 1000, 1000-5000, or greater than 5000 acres), and fuel loadings (800, 1750, and 3000 lbs/acre). For a given set of inputs, this model-based tool returns forecasts of where smoke plumes from the selected individual fire would travel, and what urban areas might be impacted by that fire.

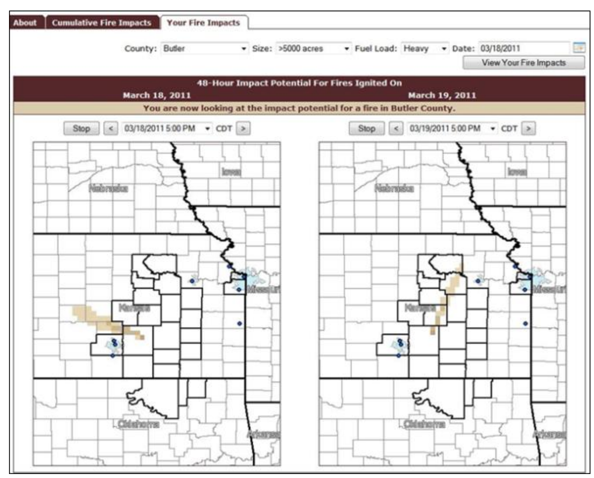
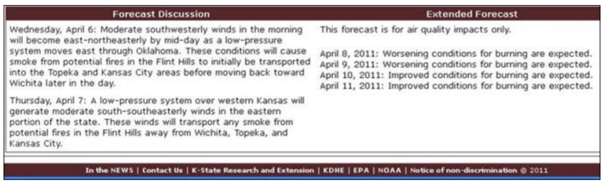


Fig. 4. Maps of individual smoke impacts (smoke plumes in light brown) from fires on March 18 and 19, 2011, from a hypothetical 5000 acre burn in Butler County, Kansas.

2.4 Forecast Discussion

Air pollution meteorologists augment information provided by the automated cumulative and individual fire impact maps with daily forecast discussions and extended outlooks (Fig. 5). These discussions and outlooks provide land managers with additional information on possible smoke impacts from fires that might be set in the Flint Hills, and provide additional expert interpretation of the guidance presented by the model-based tools. The forecast discussion focuses on current and next-day conditions, while the extended output provides up to five days of advance notice when conditions for burning are expected improve or worsen.



Forecast Discussion	Extended Forecast
Wednesday, April 6: Moderate southwesterly winds in the morning will become east-northeasterly by mid-day as a low-pressure system moves east through Oklahoma. These conditions will cause smoke from potential fires in the Flint Hills to initially be transported into the Topeka and Kansas City areas before moving back toward Wichita later in the day. Thursday, April 7: A low-pressure system over western Kansas will generate moderate south-southeasterly winds in the eastern portion of the state. These winds will transport any smoke from potential fires in the Flint Hills away from Wichita, Topeka, and Kansas City.	This forecast is for air quality impacts only. April 8, 2011: Worsening conditions for burning are expected. April 9, 2011: Worsening conditions for burning are expected. April 10, 2011: Improved conditions for burning are expected. April 11, 2011: Improved conditions for burning are expected.

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Fig. 5. Forecast discussion and extended outlook prepared for the April 6-7, 2011, near-term forecast period and the April 8-11, 2011, extended forecast period.

3. GENERATING THE GUIDANCE

The cumulative and individual fire impact maps from the prescribed burn DSS are generated from output of a real-time smoke modeling system based on the USDA Forest Service (USFS) BlueSky Framework (Larkin et al., 2009) and the National Oceanic and Atmospheric Administration (NOAA) Hybrid Single Particle Lagrangian Integrated Trajectory Model (HYSPLIT) (Draxler and Hess, 1997, 1998). The USFS BlueSky Framework provides a centralized software system for interconnecting fire science data and models to predict smoke impacts, and has been successfully implemented in various real-time environments (Strand et al., 2012; Craig et al., 2007; Craig et al., 2012) The components of the real-time modeling system are summarized in Fig. 6.

The DSS tools are based on a matrix of 48-hr HYSPLIT dispersion model simulations of smoke emitted from hypothetical fires at various locations throughout the Flint Hills. HYSPLIT simulations are driven by meteorological forecasts from the North American Mesoscale model at 40 km resolution. HYSPLIT is configured in a chemically inert puff mode, with a 15-km resolution receptor grid covering eastern Kansas.

The HYSPLIT simulations are executed through the BlueSky Framework, which is configured to provide fire emission rates with the Fire Emissions Production Simulator (FEPS) (Anderson et al., 2004) and determine plume heights based on the Briggs plume rise methodology as implemented in FEPS. All fires are assumed to burn evenly across the landscape for 8 hours (10 a.m. to 6 p.m.), and are represented by a constant emission rate through the burn period. Fire emissions are assumed to occur exclusively in the flaming mode, with no smoldering or residual components.

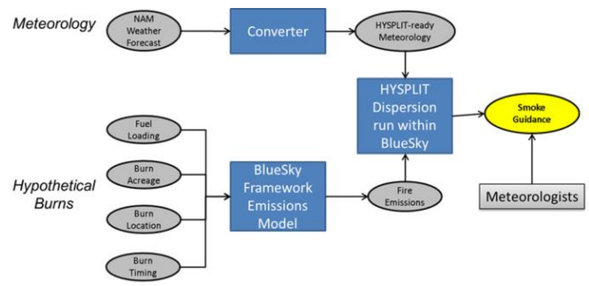

Fig. 6. Overview of the real-time smoke modeling system used to provide guidance to the KDHE prescribed burn DSS. Gray ovals represent data inputs or outputs, while blue boxes represent processing steps.

For the individual fire impact maps, HYSPLIT simulations are performed for a pre-determined set of hypothetical fire locations (usually the centroid of a county or sub-region), burn sizes, and fuel loadings. This involves hundreds of executions of the BlueSky Framework and HYSPLIT. Hourly ground-level smoke concentrations from each simulation are mapped at 15-km resolution using the MapServer Geographic Information Systems (GIS) capability embedded within the BlueSky Framework. Hourly smoke plume forecasts can be viewed for any fire location, size, or fuel loading through the DSS website (Fig. 4).

For the cumulative fire impact maps, HYSPLIT simulations are carried out for a series of simultaneous hypothetical fires across the Flint Hills region. This forecast assumes a worst-case but frequently observed scenario in which multiple fires occur simultaneously. It also assumes worst-case burn size and fuel consumption estimates based on observed burn conditions in prior years when air quality in downwind cities exceeded the NAAQS. Color-coding for the cumulative impact maps is based on two factors: (1) whether the urban areas are significantly impacted by smoke from all fires in a cumulative sense, and (2) whether smoke from an individual county or sub-region significantly impacts the urban areas.

4. EVALUATING THE GUIDANCE

4.1 Forecast Verification

Smoke forecasts from the prescribed burn DSS were evaluated against daily observations of smoke transport from fires into Wichita, Topeka, and Kansas City during April 1-30, 2011. Although the guidance was not always followed (burning occasionally took place when adverse smoke impacts were forecast), the practice of burning on days when burning was not recommended provided the opportunity to evaluate the DSS. Both model-generated and human-augmented next-day forecasts were evaluated, excluding days when air quality was impacted by regional smoke from fire outside the Flint Hills region.

Categorical forecast verifications for all days in April 2011 are shown in Fig. 7. The forecast verifications for “critical” days when observed ozone levels in any major metropolitan area reached an Air Quality Index (AQI) of 75 or greater are also presented in Fig. 7. Accuracy statistics are shown in Table 1.

a)

Smoke Predicted?		Smoke Observed? Yes	Smoke Observed? No
	Yes	18	7
	No	2	16

b)

Smoke Predicted?		Smoke Observed? Yes	Smoke Observed? No
	Yes	18	9
	No	2	14

c)

Smoke Predicted?		Smoke Observed? Yes	Smoke Observed? No
	Yes	3	0
	No	0	0

Fig. 7. Forecast performance tables for (a) Human-augmented and (b) model-generated forecasts for all days in April 2011, and (c) human-augmented and model-generated forecasts for critical days only.

Forecast	Percent Correct	Probability of Detection	False Alarm Rate
Human-augmented	79%	90%	28%
Model-generated	74%	90%	33%
Critical days only	100%	100%	0%

Table 1. Forecast summary statistics for April 2011.

Forecasts provided through the prescribed burn DSS successfully predicted smoke transport from Flint Hills fires into Wichita, Topeka, and Kansas City. The forecasts had a probability of detection (POD) of 90% for all days in April 2011, and a POD of 100% for critical days. Furthermore, automated model forecasts augmented by air quality meteorologists added value in predicting adverse air quality impacts. The forecasts from this DSS were accurate, and provided guidance to stakeholders on burn times and locations to avoid adverse air quality impacts, especially on days when meteorological conditions were conducive to ozone formation.

4.2 Case Study Demonstration

A case study is presented here to demonstrate how this DSS can be a useful tool for mitigating smoke impacts from prescribed burns. On April 12, 2011, the observed 8-hr ozone concentration in Topeka was 84 ppb (122 on the AQI), which exceeded the NAAQS. Smoke and precursor emissions from Flint Hills fires were prevalent in the region (Fig. 2), and may have contributed to the adverse air quality in Topeka.

According to the forecast discussion issued on April 12, 2011, “light to moderate southerly winds ahead of an approaching cold front will carry smoke from potential fires in the eastern Flint Hills into Topeka.” The cumulative fire impact forecast map from the DSS for April 12 (Fig. 8) also indicated that fires from several counties in the eastern Flint Hills (indicated by yellow and red on the map) had the potential to contribute to adverse air quality in urban areas, and therefore burning in these counties was not advised.

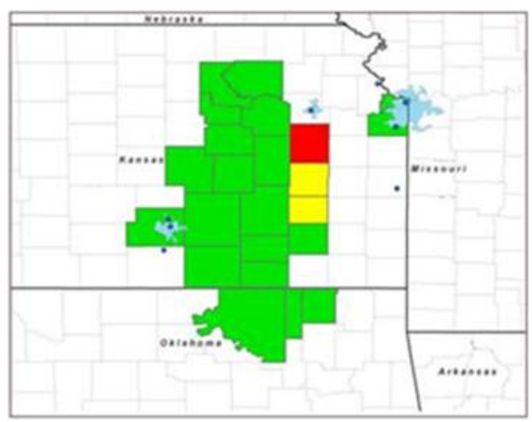

Fig. 8. Cumulative fire impact map forecast for April 12, 2011, from the prescribed burn DSS.

On April 11, the forecasted southerly winds verified, fires were set in the Flint Hills, and smoke and precursor emissions from those fires, especially from the eastern Flint Hills, impacted Topeka. It should be noted that in the cumulative impact map (Fig. 8), only the counties predicted to be upwind of Topeka on April 11 were highlighted for adverse air quality impacts. Other counties, denoted in green, were not predicted to be directly upwind of Topeka, and therefore the DSS did not advise against burning in those counties.

5. CONCLUSIONS

A real-time decision support system was developed for KDHE to help land managers in the Flint Hills region of Kansas mitigate adverse air quality impacts from prescribed rangeland burns. The guidance tools are made available to land managers through an intuitive web interface. This DSS, which combines automated model-based smoke forecast guidance with expert evaluation by air quality meteorologists, is a valuable tool to guide prescribed burn planning and mitigate smoke impacts.

During the spring 2011 prescribed burn season, model forecasts augmented by air quality meteorologists were accurate and added value in predicting adverse air quality impacts in Wichita, Topeka, and Kansas City. This was demonstrated through a quantitative forecast performance evaluation of the DSS for April 2011, and through an April 11, 2011, case study of Flint Hills burns impacting an urban area.

This DSS has been operating for the past two burn seasons and will be operational again during the upcoming 2013 burn season.

6. REFERENCES

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