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Adapting Australia's Grassland Fire Danger Index for the United States' Central Plains

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ABSTRACT

The Grassland Fire Danger Index (GFDI) is an index that was developed in Australia, and then adapted and calibrated (cGFDI) for use in the United States' Central Plains. Strengths of this index include: the ability to produce a digital hourly forecast out to 7 days with a spatial resolution of a few kilometers, a focus of parameters specific for grassland areas and fuels, and a better understanding by fire and emergency managers for burn permit and grassland fire decision support. A case study from 15 April 2008 is presented in which there were numerous large grass fires across central and southeast Kansas. The cGFDI values were clearly in the "extreme" category across the main threat area, central and southeast Kansas, providing excellent decision support. A second case study on 17 June 2009 is presented for a time where the cGFDI was critical during an unusual nocturnal fire associated with a heat burst.

1. Introduction

Forecasting fire potential in the Central Plains of the United States has long been a challenge due to the presence of expansive grassland prairies, in which fires have the potential to burn thousands of acres in a very short period of time due to the fine fuels. Various fire weather forecasting indices have been developed for this region and some have shown skill. However, these indices have typically been a one-day forecast with each index value representing a large area, sometimes over 16,000 km^2 (10,000 square miles).

As the fire weather program within the National Weather Service (NWS) grew significantly for much of Kansas and Nebraska in 2006, daily fire weather planning forecasts as

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well as fire weather watches and warnings began. Several fire weather program leaders met with federal fire management officials across this region before these new products were issued to determine appropriate criteria for Red Flag Warnings (RFWs). Without a comprehensive database of what conditions typically caused fires to become explosive in this region, criteria were selected during these discussions using a "best guess" based on experience from these individuals. These selected criteria differed as climatology changes from the high plains in the west to the central plains in the east.

This paper will focus on, what the authors believe to be, a superior method to forecast explosive fire behavior potential for grassland areas in the United States. This method was gathered from the Australia Bureau of Meteorology (BOM) then calibrated by data used in case studies made during the one-year development period (spring 2007 through spring 2008) in grassland areas in the central United States.

2. Information Sharing

Several fire weather forecasters were selected to travel to Australia from January through March 2007 to aid in forecasting for another unusually active fire weather season in southeast Australia. This was an opportunity to not only help another country during a critical weather period, but also an opportunity to share science, techniques, technology, and ideas between the BOM and the NWS.

During training and a three-day induction course, the grassland fire danger index (GFDI), which is used for the grasslands of Australia, especially the eastern portion of the country, was presented. It was originally defined by A.G. McArthur in 1966, and continues to be widely accepted in Australia. It is "designed to provide regional warnings of fire danger" (Sullivan

2008), and allows for a forecast several days in advance at a fine spatial and temporal resolution. The equation is:

$$\mathrm{FDI} = 10\text{^}(0.009254 - 0.004096*(100 - C)^{1.536} + 0.01201*T + 0.2789*\sqrt{V} - 0.09577*\sqrt{RH})$$

where C = curing (%), T = temperature (^{o}C), V = sustained wind (km/hr), and RH = relative humidity (%). Index values are categorized as low, moderate, high, very high, and extreme. See Tables 1 and 2 for more information on expected fire behavior at various indices.

This continuous function allows for the use of very high-resolution data and is a relatively simple mathematical equation for quick calculation by a software program. After many years of research and development in Australia, the GFDI was found to be scientifically sound for grassland fires (Noble 1980).

3. GFDI Details/Development

After evaluating the GFDI's use in Australia, the decision was made to move forward with development of the GFDI that could be useful for the U.S. Central Plains. The GFDI equation is relatively simple for NWS forecasting software, the Graphical Forecast Editor (GFE) (Hansen et al. 2001), to incorporate and it can be calculated using an hourly temporal resolution for up to seven days. Additionally, there is minimal impact on forecasters' workload, as temperature, wind, and dewpoints are already forecast routinely in the GFE. Therefore, curing was the only parameter that needed to be established before beginning to issue the GFDI product.

Curing is a measure of the moisture content of a fuel, with values ranging from 0 to 100%. Zero percent represents premature, green grass typically seen from late spring to mid-summer across the Central Plains. One hundred percent represents fully cured, dry grass typically seen from late fall into early spring across the Central Plains.

In the spring, curing values fall at varying rates across central and eastern Kansas. Many ranchers burn their pastures during the first two weeks or so of April to allow for abundant new grass growth for cattle along the Flint Hills in eastern Kansas. Conversely, many of the pastures in central and south-central Kansas are allowed to "green up" slowly and naturally. This causes a large variation in curing values across central and eastern Kansas during spring. Curing values during the fall are much more consistent across the area. The high variability in the spring underscores the need for high-resolution curing data that can better serve the customer.

To improve the quality of data during the spring period, curing values are obtained from observers who call their curing values into the NWS Wichita, Kansas office once per week. The number of curing observers across the forecast area represents each of the different homogeneous growing regions and the spatial variability that might be encountered within that region. In the Wichita forecast area, data from thirteen curing observers were initially utilized for the test period. Additionally, the flexibility was utilized to include "ad hoc" observations via field trips performed by staff to serve other aspects of weather forecast office (WFO) outreach and field work programs.

Examples of observers recruited are cooperative observers, spotters, emergency managers, and volunteer firemen who are dependable and knowledgeable about grass fires in their area. These observers call their observations into the WFO each Monday, and are encouraged to call in supplemental observations as conditions warrant. Observations are entered as point data into an internal intranet web form and then ingested into the GFE. The point data are then interpolated across the domain using a Barnes objective analysis.

To promote more consistent observations among observers, a curing guide was created and given to each observer. This guide contains information about the general curing of grasses in this region, instructions on what types of grasses to observe (e.g., native pastures, not cultivated fields), and photographs of many different curing values for comparison. Quality control of the curing observations can be done via Moderate-Resolution Imaging Spectroradiometer (MODIS) Terra satellite imagery as well as via NWS employee travel through the forecast area.

4. Operational Forecasting

Aside from a daily fire danger index, other benefits of the GFDI include serving as criteria for Red Flag Warnings (RFWs) and county officials' decision support for issuing burn permits and fire mitigation planning activities. Some of these benefits were anticipated, however, the use of the GFDI for burn ban issuances, as discovered through collaboration with several county officials, was an unexpected derivative of this product.

a. Criteria for Red Flag Warnings

The following criteria were used in determining necessary RFWs: the presence of critical fuels, relative humidity 20% or below, and sustained winds at or above 24 km/hr (15 mph) or gusts of 32 km/hr (20 mph) or more. These warning criteria had been in place since WFO Wichita began issuing these warnings in October 2006. The same warning criteria were used for Russell in central Kansas and Coffeyville in southeast Kansas, despite a noteworthy difference in climate and grass type. The GFDI offers a more accurate representation of the explosive grassland fire danger potential as it utilizes a "sliding scale" for the above critical variables, improved temporal and spatial resolution to better incorporate differences in antecedent land surface conditions (e.g., observed curing, burn scars, etc…), and a better reflection of fire behaviors associated with 1-hour fuels.

With information in hand from previous planning discussions with the fire weather community, the authors determined that a GFDI value of 50 for any length of time would be a good trigger for an RFW and corresponded well to values found in Tables 1 and 2. From this, regular verification and calibration was performed during the test period (see case 15 April 2008 case study below). Once calibrated, operational implementation was ready for the calibrated GFDI (hereafter referred to as the cGFDI).

Because the cGFDI formula allows for a sliding scale of the different parameters, it allows the possibility that with higher wind speeds, fires could still get out of control even with relative humidity values higher than previous levels thought to be critical and vice versa. This is consistent with the feedback received from fire weather customers. B. Waln of the U.S. Fish and Wildlife Service (2008, personal communication) confirms that when fuels are mostly cured, a relative humidity of 30% is sufficient when combined with strong winds. It is important that any index that is used agrees with what a federal fire management coordinator is sensing from what he or she sees in the weather.

Verification of the cGFDI was done by collecting the observed elements used to calculate the cGFDI for each county, recalculating an “observed” cGFDI, and then comparing these values to the forecast cGFDI. This was achieved via use of a spreadsheet.

b. Issuing burn permits

After the cGFDI was being issued operationally, B. Guy, the emergency manager in Reno County, Kansas experimented using the cGFDI for issuing burn permits within the county.

Previous to this test, there were daily burn permits as well as week-long burn bans that would be issued based on antecedent fuel conditions as well as current weather conditions.

For a burn ban, Mr. Guy would poll the county fire chiefs after a dry period to see if they thought a burn ban should be issued. A burn ban is issued through the county commission for a week at a time, and frequently the county will receive rainfall during such a week. Despite improved burning conditions, the burn ban would remain in effect until its expiration date. Therefore, Mr. Guy decided to try using the cGFDI on a daily basis to determine whether or not a burn ban should be issued.

With a cGFDI of “very high” or “extreme,” no burning would be allowed. Moreover, during a dry period, such as the one experienced in the early summer of 2009, a burn ban would be issued 3 days in advance to give fire managers time and resources to control fire leading up to and during the critical period. Otherwise, a cGFDI of “low,” “moderate,” or “high” and when wind conditions and other statutory requirements were met, burning would be allowed.

When Mr. Guy was asked how well this has been working, he said, “I personally feel that it has worked very well. The fire chiefs seem to agree with that thought. I believe that we will continue to use this tool as long as it is available to us” (2009, personal communication). Several other emergency managers have begun the same practice in their counties.

5. Case Reviews

a. 15 April 2008

The GFDI was implemented on an experimental basis for the Wichita forecast area on 9 April 2008. Within a few days, a day with numerous large fires occurred across central and southeast Kansas. While green-up had begun across the affected area, a large amount of cured grass still existed, similar to what is shown in Fig. 1. Observers reported curing values generally 85 to 95% across central, south-central and southeast Kansas on 15 April. Sustained winds of 40 and 60 km/hr (25 and 40 mph) were observed with frequent gusts to 72 to 80 km/hr (45 to 50 mph) throughout central and south-central Kansas. R. Hauck, fire management coordinator with the Kansas Forest Service (2008, personal communication), considered these conditions to be extreme and stated "my gut would have told me it was a 'no-go' day." Another fire management coordinator observed that "gusts were frequent to the point of almost being sustained in the Manhattan and Great Bend areas."

Several large fires were seen on radar and satellite imagery on this day. One of these fires was in northern McPherson County, about 30 to 40 km (20 to 25 mi) southeast of the city of Salina. This fire was moving toward Salina rapidly. The story of this fire was carried on local television as it threatened homes in that area. In Figure 2, the red spots are fires that were detected by satellite. Notice the smoke plume associated with the McPherson County fire, which is heading toward Salina. Additionally, note the large number of fires including a few fires across the Flint Hills (the brown region between Wichita and Kansas City) which may have been controlled burns by area ranchers.

The curing value and wind speeds would have warranted a Red Flag Warning by NWS Wichita using the afore-defined criteria. The critical element that would have hindered proper identification of a Red Flag day using the previously defined warning criteria established in October 2006 was relative humidity. Minimum values of relative humidity were observed between 20 and 30 percent, with a few locations only dropping to near 35 percent that day. This would not have warranted a Red Flag Warning using the "old" criteria. However, the GFDI did properly predict a Red Flag day at a couple locations with values reaching into the "extreme" category (Fig. 3), but overall came up short of what was expected based on the difficulty in fire suppression.

In an attempt to improve and validate the GFDI formula, indices were calibrated from the 15 April 2008 observations. These were stratified into three categories: sustained winds, an average of the sustained wind and wind gust, and wind gusts. Most of the sites that met warning criteria with the averaged winds also met warning criteria with sustained winds. Table 3 shows how the GFDI values differed based on the type of wind speed used. These results showed that the sustained wind did not show the severity of the situation as well as the averaged category. Additionally, the wind gust-only category resulted in a false alarm and was deemed too aggressive.

To further this argument, under some conditions, wind gusts can vary significantly in a short period, changing fire behavior dramatically. Shifting winds can also cause the size of the head fire to increase rapidly or turn a flank fire into a head fire (Rasmussen and Fogarty 1997). With so many explosive grass fires and such strong winds in this case, it was believed that the 15 April 2008 event was more than a borderline warning day, as the sustained-wind-only GFDI recalculation suggested. Therefore, the final decision was made to calibrate the GFDI's formula to use a wind speed that was the resultant average of the sustained wind and the wind gust. The cGFDI resulted in a better differentiation between critical and non-critical fire potential quite well. Table 3 illustrates the results of this calibration for the 15 April 2008 case.

b. 17 June 2009

A somewhat unusual case occurred on 17 June 2009, when weakening showers moved through central Kansas. Several locations experienced a heat burst as these showers passed through and dissipated, increasing temperatures from the lower and middle 80s to just over 100°F at approximately 11 pm. Relative humidity plummeted as well. McPherson, Kansas observations through the event are shown in Table 4.

During this time, there was a grass fire along Interstate 70. The fire occurred within a right-of-way that had been mowed several times and therefore had a layer of dead thatch under the growing grass. The weather conditions that night, along with the dead thatch allowed the green grass to burn. A volunteer fireman that responded to this fire said that he was surprised how well the green grass in this right-of-way burned, but also stated that the grass did not burn into the adjacent pasture where there was no dead thatch.

Curing values were approximately 25% at this location during this time. Using the observations at McPherson to compute the cGFDI at the time of the fire yields a value of “low.” The fire was not difficult to suppress as it did not burn into the adjacent pasture, which was representative of the curing value. Therefore, even with the low relative humidity and strong winds, the low cGFDI value was a great asset in decision support services based on this firefighter’s account.

6. Conclusions

Grass fires have the potential to quickly become explosive. Since grass is a one-hour fuel, changing weather conditions have a rapid impact on this explosive fire potential. Therefore it is important to have a fire danger index that can accurately portray the fire danger on a more refined spatial and temporal scale. The cGFDI capitalizes on this resolution with minimal impact on forecaster workload while improving on the sciences with observed curing values of the fuels, a critical element in grassland fire behavior prediction.

To facilitate a successful GFDI program, the importance of trained, reliable curing observers and proper quality control of temperature, relative humidity, and wind forecasts are of vital importance. A loss of attention in these areas could adversely affect the cGFDI.

Preliminary findings indicate that the cGFDI has improved performance in the fire weather program at NWS Wichita and could do so for other WFOs that serve areas with grassland prairies. The suggested use of an average of the wind and wind gust speed produced the most favorable result during the test period of the GFDI (resulting in the cGFDI) and was further validated via the 15 April 2008 and 17 June 2009 events. Evaluation will continue on the usefulness and effectiveness of the cGFDI.

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REFERENCES

A.G. McArthur, Grassland Fire Danger Meter Mk IV 1973. Bush Fire Council of N.S.W. Officer Training Module CL/4 - Fire Behaviour Second Edition. Grasslands FDI's - Fire Behavior Relationships. [Available online at http://www.firebreak.com.au/grass-behave.html].

Hansen, T., M. Mathewson, T.J. LeFebvre, and M. Romberg, 2001: Forecast Meteorology Using the GFE Suite. 17th Int. Conf. on Interactive Information Processing Systems for Meteorology, Oceanography, and Hydrology, Albuquerque, NM, Amer. Meteor. Soc., 42-46.

Nicholson, K, 2008: Deadly Ordway Fire Started By Human. *The Denver Post,* 22 April. [Available online at http://www.denverpost.com/news/ci_9014487.]

Noble, I.R., G.A.V. Bary, and A.M. Gill, 1980: McArthur's fire-danger meters expressed as equations. *Australian Journal of Ecology*, **5**, 201-203.

Rasmussen, J.H.; L.G. Fogarty, 1997: Fire growth, fire behavior and firefighter safety – A review of the lessons from "A Case Study of Grassland Fire Behaviour and Suppression: The Tikokino Fire of 31 January 1991". *Fire Technology Transfer Note,* **Report No. 14**.

Stevens, R. Fuel Loading, Fuel Moisture Are Important Components of Prescribed Fire. *Ag News and Views* - *Wildlife,* January 2004.

Sullivan, Andrew, 2008: Grassland Fire Danger Meter. Available online at http://www.csiro.au/products/GrassFireSpreadMeter.html.

TABLES AND FIGURES

Fire Behavior Relationships										
FIRE DANGER INDEX	RATE OF SPREAD (km/h)	DIFFICULTY OF SUPPRESSION	MAXIMUM AREA AT VARIOUS TIMES FROM START (hectares)**				AVERAGE FINAL SIZE OF FIRE (hectares)	FLAME HEIGHT (Meters) IN		
			½ hr	1 hr	2 hr	4 hr		Sparse Pasture	Average Pasture	Heavy Pasture
2	0.3	**Low.** Headfire stopped by road and tracks.	3	20	80	320	3	0.3	1.0	3.0
5	0.6	**Moderate.** Head attack easy with water.	6	40	160	640	16	0.6	2.0	3.5
10	1.3	**High.** Head attack generally successful with water.	15	90	360	1440	65	1.0	3.0	5.5
20	2.6	**Very High.** Head attack will generally succeed at this Index.	35	210	840	3360	450	2.0	3.5	7.0
40	5.2	**Very High.** Head attack may fail except in favorable circumstances and close back burning to the head may be necessary.	80	480	2000	8000	2400	2.5	5.0	9.0
50	6.4	**Extreme.** Direct attack will generally fail. Backburn from a secure good line with adequate manpower and equipment. Flanks must be held at all costs.	105	630	2500	10000	4000		5.5	10.0
70	9.0		170	1000	4000	16000	10000		6.0	11.0
100	12.8		300	1800	7000	28000	32000		7.0	13.0
**Note: This assumes that the head fire burns unchecked. Suppression action which is only partially successful will reduce these areas.										

Table 1. Expected fire behavior relationships for various GFDI values. With an index of 1 or 2, fires will either not burn or burn so slowly that control presents little difficulty. At an index of 100 they will burn so hot and fast that control is almost impossible. The intensity of a fire and its difficulty of control are also affected by the quantity of grass in the pasture. Heavy pastures burn faster and with a greater intensity than light pastures. In addition, the finer the grass, the faster a fire will travel. The rates of spread are average values for fires in annual and perennial pastures carrying a continuous body of fuel and occurring on level to undulating ground. Spread rates will be less than indicated in sparse, discontinuous pastures and will also vary according to topography (McArthur 1973).

Fire Behavior Relationships										
FIRE DANGER INDEX	RATE OF SPREAD (mph)	DIFFICULTY OF SUPPRESSION	MAXIMUM AREA AT VARIOUS TIMES FROM START (acres)**				AVERAGE FINAL SIZE OF FIRE (acres)	FLAME HEIGHT (feet) IN		
			1/2 hr	1 hr	2 hr	4 hr		Sparse Pasture	Average Pasture	Heavy Pasture
2	0.2	**Low.** Headfire stopped by road and tracks.	7	50	200	790	7	1	3	10
5	0.4	**Moderate.** Head attack easy with water.	15	100	400	1580	40	2	7	11.5
10	0.8	**High.** Head attack generally successful with water.	35	220	890	3560	160	3	10	18
20	1.6	**Very High.** Head attack will generally succeed at this Index.	85	520	2080	8300	1100	7	11.5	23
40	3.2	**Very High.** Head attack may fail except in favorable circumstances and close back burning to the head may be necessary.	200	1190	4940	19800	5900	8	16.5	29.5
50	4.0	**Extreme.** Direct attack will generally fail. Backburn from a secure good line with adequate manpower and equipment. Flanks must be held at all costs.	260	1560	6180	24700	9900		18	33
70	5.6		420	2470	9900	39500	24700		20	36
100	8.0		740	4450	17300	69200	79000		23	43

**Note: This assumes that the head fire burns unchecked. Suppression action which is only partially successful will reduce these areas.

Table 2. Same as Table 1, converted to US units.

15 April 2008 Weather Conditions Across Central and Southeast Kansas								
County in KS	**Max T (C)**	**Min RH (%)**	**Sustained Wind (km/hr)**	**Wind Gust (km/hr)**	**Curing (%)**	**GFDI (Sustained Winds)**	**GFDI (Average of Sustained and Gust)**	**GFDI (Wind Gusts)**
Russell	27	20	56	74	88	64	93	131
Barton	25	23	65	80	87	77	103	136
Saline	22	33	50	72	91	38	61	93
McPherson	22	33	61	82	89	55	83	122
Chase	23	24	50	67	94	53	77	108
Reno	22	33	61	82	90	58	87	128
Harvey	22	31	54	65	92	49	62	77
Butler	23	29	52	76	93	50	83	132
Greenwood	23	24	50	67	94	53	77	108
Woodson	22	27	52	67	93	51	70	95
Kingman	23	27	56	70	89	52	69	91
Sedgwick	22	27	54	69	94	58	79	107
Harper	24	29	52	67	93	51	71	96
Sumner	23	29	53	76	92	50	81	126
Cowley	23	29	54	61	93	55	64	74
Elk	22	18	32	40	94	24	30	37
Neosho	20	32	46	63	92	32	46	66
Chautauqua	22	27	41	54	94	31	43	58
Montgomery	21	31	43	56	93	30	41	54
Labette	21	31	35	52	93	20	31	46

Table 3. 15 April 2008 weather conditions across central and southeast Kansas. For each county listed, the maximum temperature, minimum relative humidity, wind, and curing were all entered into the GFDI formula. The corresponding values of GFDI show the difference when using the sustained wind, an average of the sustained wind and wind gust, and the wind gust. Red colors in the RH column indicate which counties would have met Red Flag Warning criteria using the old criterion of 20% RH, while the GFDI column colors indicate Red Flag Warning criterion using the new GFDI criteria. Yellow indicates very high fire danger and red indicates extreme fire danger.

Weather Conditions at McPherson, KS 17 June 2009			
Time (LT)	Temperature (F)	Relative Humidity (%)	Wind (MPH)
1042 pm	84	40	10 Gust 30
1115 pm	87	36	17 Gust 23
1120 pm	88	29	30 Gust 37
1122 pm	91	23	40 Gust 52
1125 pm	94	20	33 Gust 52
1131 pm	100	15	29 Gust 52

Table 4. Weather conditions at McPherson airport in McPherson, KS on 17 June 2009. These conditions occurred during a heat burst as a weakening thunderstorm passed over the area.

Figure 1. An example of antecedent fuel conditions similar to what was observed in southeast Kansas in mid-April 2008. This photo was taken on April 17th, 2008 in southeast Colorado. Photo courtesy of Tim Mathewson.

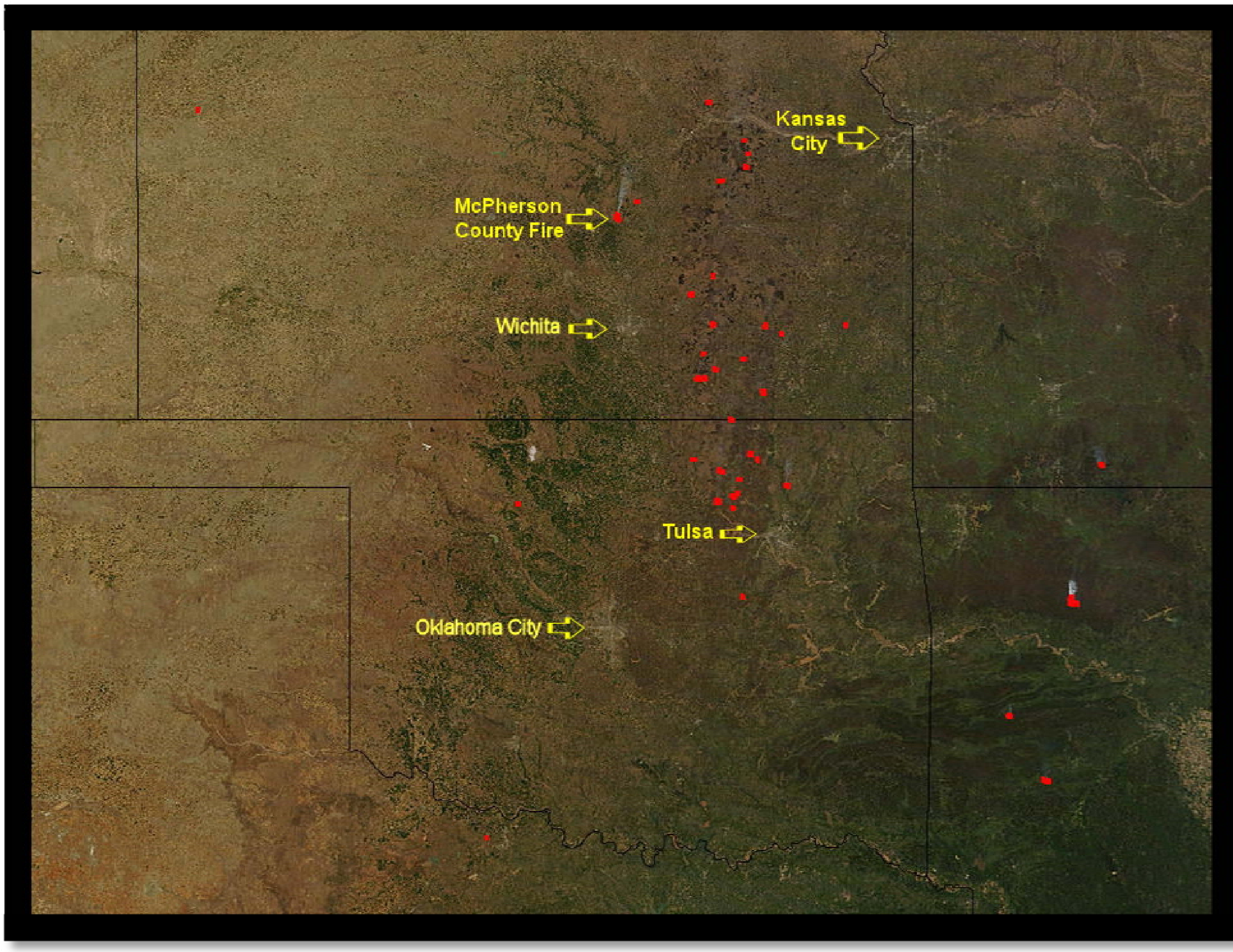

Figure 2. MODIS satellite image from 15 April 2008. Some of the larger cities are labeled for reference. Red spots are large fires detected by the satellite. The darker green area from west of Oklahoma City to west of Wichita is the winter wheat belt, and the brown area to the east of Wichita is considered the Flint Hills.

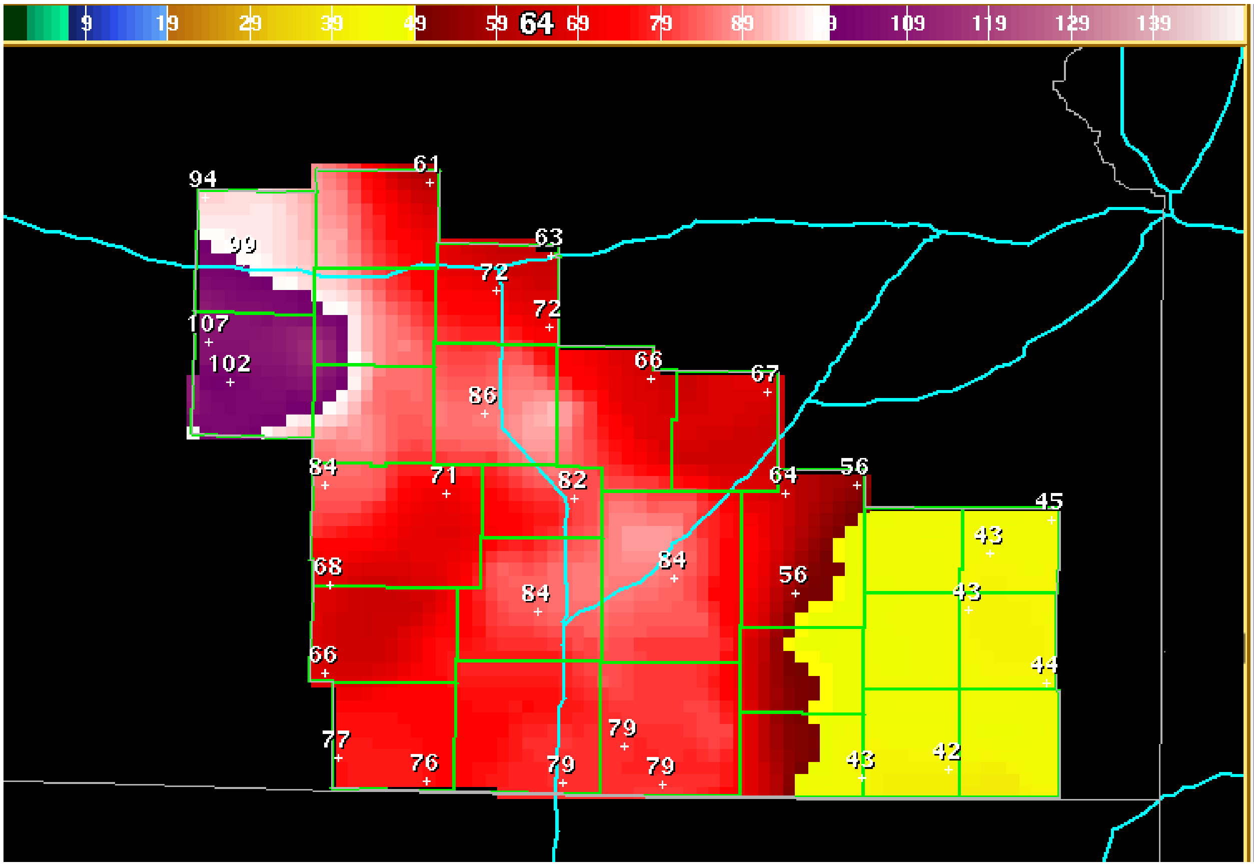

Figure 3. GFDI image from the Graphical Forecast Editor (GFE) for the 15 April 2008 case. The color scale is shown above the image. Dark green = low fire danger, light green = moderate fire danger, blue = high fire danger, brown/yellow = very high fire danger, red extreme fire danger. Interstate highways are shown in cyan.