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### Spatial Distribution of Grassland Fires at the Regional Scale Based on the MODIS Active Fire Products

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1	Spatial Distribution of Grassland Fires at the Regional Scale
2	Based on the MODIS Active Fire Products
3	
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23	into continuous surfaces. In this study, kernel density estimation was applied to grassland fire
24	events in the eastern Inner Mongolia of China, based on Moderate Resolution Imaging
25	Spectroradiometer (MODIS) Terra and Aqua daily active fire data from 2001 to 2014. The
26	bandwidth choice was based on the mean random distance method. Annual and seasonal kernel
27	density maps were produced, showing that the spatial patterns of grassland fire events remained
28	temporally consistent. These results were used to create grassland fire risk zones on the basis of
29	the mean density values in the study area. Grassland fire prevention and planning may focus on
30	high-risk areas identified using this method.
31	
32	Additional Keywords: Grassland fire; MODIS; Kernel density estimation; Fire risk zone
33	
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45	constitutes one of the largest sources of global greenhouse gas emissions (Hao and Liu, 1994;
46	Oom and Pereira, 2013). Grassland fires are also harmful for agricultural and livestock production.
47	Annual fires may result in increased soil erosion, soil degradation, loss of life and property,
48	diminished grass resources, and reduced biodiversity (Chuvieco et al., 2010).
49	In the North American Great Plains and desert grasslands of southwestern North America,
50	grassland fires mainly occur in spring and early summer, prior to the summer rainy season (Gosz
51	et al., 1995; Gosz and Gosz, 1996; Engle and Bidwell, 2001). In the arid and semi-arid grasslands
52	of South America, most grassland fires are repeatedly ignited to suppress undesirable woody
53	vegetation (Bóo et al., 1996; Bóo et al., 1997; Guevara et al., 1999; Martinez Carretero, 1995). In
54	Africa, widespread fires frequently burn the savanna each year, and most fires occur in dry
55	seasons (June-August) (Danthu et al., 2003; Laris, 2002; Mbow et al., 2000; Reid et al., 2000;
56	Sheuyange et al., 2005; Snyman, 2004). In Australia, vast tracts of savanna are burnt annually in
57	the dry season (May–November) under relatively severe climatic conditions (Edwards et al., 2001;
58	Gill et al., 1996). As a major part of Asian grasslands, arid and semi-arid grasslands cover
59	Mongolia and the Inner Mongolia of China. Annual fires are also frequent in these areas. The
60	cycle of fire occurrence is about 3-6 years, and over 90% occur in spring and autumn (Liu et al.,
61	1999; Zhou, 1995).
62	In order to estimate fire risk, fire managers and scientists have studied the phenomenon in terms of
63	frequency, severity, size, probability, spatial pattern and distribution (Amatulli et al., 2007). Fire
64	risk assessment would help the managers in making fire prevention and management plans
65	according to spatial and temporal patterns in the high risk zones. Mapping fire risk zones using

spatial and temporal models of wildland fire history or fire occurrence is essential from ecological,

67 social and economic perspectives (Pleniou et al., 2013).

68	To assess fire risk, data on the historical fire occurrence and environmental factors must be
69	available to fire managers or scientists. However, it is often the case that the historical fire records
70	do not contain the proper information regarding fire events, such as the mean or approximate
71	geographical location, size, perimeter and severity. Although a fire event is often treated as a point
72	in x- and y-coordinates, point recognition process of events would lead to serious positional
73	inaccuracies because the exact location of ignition point is usually unknown (Amatulli et al., 2007;
74	Koutsias et al., 2004; Kuter et al., 2011).Human activities are closely associated with fire
75	occurrences. Data on human and economic factors are largely sourced from administrative records
76	at different spatial scales. Combining these inaccurate fire records and administrative records
77	regarding influencing factors may result in substantial errors when we examine the spatial patterns
78	of fire and their influencing factors. In other words, risk assessment that integrates firs evens and
79	human factors would benefit from the continuous form of fire events because of the ease of
80	integration with data on human activities and reduced error propagation in the process (Syphard et
81	al., 2007; Martinez et al., 2009; Martinez-Fernandez et al., 2013). Therefore, a reliable method is
82	necessary to convert the fire occurrence point data into a continuous surface representing the fire
83	occurrence density and to carry out the fire risk zoning exercise (Koutsias et al., 2004).
84	There are several interpolation techniques used to convert data from fire points to continuous
85	surfaces. As a commonly preferred method, Kernel density estimation (KDE) produces a surface
86	that is a nonparametric estimate of the underlying unknown intensity function (Waller, 2004). This
87	method has been widely used to convert historical forest fire occurrence data into continuous fire
88	occurrence density surfaces, to identify the spatial patterns of fire occurrence at the regional or

89	local scales and to assess the forest fire risk associated with the influencing factors (Amatulli et al.,
90	2007; Koutsias et al., 2004; Kuter et al., 2011). These analyses suggest that this type of spatial
91	pattern information is very useful for predicting and managing forest fires.
92	Most grassland involves annual vegetation, and these grass fuels can ignite every year in suitable
93	environments. In comparison, grassland fires release energy at a rate lower than that of forest fires
94	(Mell et al., 2005). Forest fires have very large ecological impacts on all of the vegetation strata in
95	a forest. However, because grassland fuels are more flammable and have lower moisture contents,
96	grassland fires occur more easily and propagate more quickly. Therefore, grassland fires may
97	represent high-risk situations, especially during suppression operations (Alexander and Fogarty,
98	2002; Linn et al., 2002). To understand and manage grassland fires, it is critical to analyze the
99	distributions of grassland fires.
100	The main purpose of this study is to reveal the spatial patterns of grassland fire events in the
101	eastern Inner Mongolia of China, which has suffered from high incidence of grassland fire, using
102	KDE methods with MODIS fire active products (from 2001 to 2014) and to demonstrate that such
103	a technique can be applied in grassland fire analysis. Seasonal and annual KDE maps were
104	produced to disclose the time dimension of fire regimes The final density map of grassland fire
105	occurrence zones shows the mean density in the study area and has potential to help improve
106	preventative management strategies of grassland fires.
107	
108	Materials and Methods

- 109 Study Area

110 The study area is located in the eastern Inner Mongolia Autonomous Region of China, between

111	41.26-53.23°N and 115.22-126.06°E (Figure 1). It is approximately 1,333 km long and 743 km
112	wide, covering a total area of 454,204 km <sup>2</sup> . The climate in the study area is a typical temperate
113	continental monsoon, with low, irregular rainfall and extreme changes in temperature between
114	summer and winter. The annual mean air temperature and precipitation are approximately -2.3°C
115	and 320 mm respectively (Zhang et al., 2013). The vegetation in the eastern Inner Mongolia
116	grassland region is made up of diverse plant communities, which are dominated by Stipa
117	baicalensis, Filifolium sibiricum and Leymus chinensis. The elevation ranges between 200 and
118	1500 m. The central region is dominated by the Daxing'An Mountains, stretching from the centre
119	of the region towards the east and west. The elevation gradually decreases, and topography
120	gradually becomes flatter. There are 36 counties and approximately 5000 villages and towns
121	scatter across the study area. Paved roads, dirt roads, and railroads are common in the region.
122	They are distributed throughout the area, with an average density of approximately 67.64 km/km <sup>2</sup> .
123	The activities of the inhabitants often lead to accidental fires. The annual frequency of fires in the
124	region is high with approximately 600 wildfires every year, which is why it was chosen as the
125	study area (Fu et al., 2001).

**127** *Data* 

In the study area, traditional methods were used to collect information on fire events via the officers of local fire protection departments. The MODIS Active Fire Data contain daily fire pixel locations that are most appropriate for analysing the spatial and temporal distributions of events. The MODIS Terra and Aqua daily active fire product data (MOD14A1 and MYD14A1) are available in our study region. The fire product data set from 2001 to 2014 was downloaded from

133	the Land Processes Distributed Active Archive Centre (LP-DAAC) using a web-based interface
134	known as Reverb, which is a replacement for the Warehouse Inventory Search Tool
135	(https://reverb.echo.nasa.gov/). This fire product is based on 1 km pixels, in which burning was
136	detected at the times of Terra and Aqua satellite overpassing under relatively cloud-free conditions.
137	A contextual algorithm that detects the strong emission of mid-infrared radiation from fires is used
138	based on brightness temperatures derived from the 4 and 11 $\mu$ m channels, enhancing the
139	sensitivity of smaller, cooler fires and minimising the detection of false positives (Giglio et al.,
140	2003; Morisette et al., 2005; Giglio et al., 2006; de Klerk et al., 2008; Hawbaker et al., 2008) <u>.</u>
141	The fire mask is the principle component of the Level 2 MODIS fire product and is stored as an
142	8-bit unsigned integer Scientific Data Set (SDS). In it, individual 1 km pixels are assigned to one
143	of nine classes (Giglio, 2013). These classes are listed in Table 1. It was found that classes eight
144	and nine of the fire mask pixel are suitable for the study area (He et al., 2013). The pixels with
145	values of eight and nine were extracted from the MOD14A1 and the downloaded rasters were
146	converted into the vector format as active fire points.
147	A land use and land cover data set of the study area was provided by the Data Centre for
148	Resources and Environmental Sciences, Chinese Academy of Sciences (RESDC)
149	( <u>http://www.resdc.cn</u> ). These data were interpreted from Landsat TM/ETM from 2010 at the scale
150	of 1:100,000. The grasslands in the study area were derived from the land use data set. Then, the
151	active fire data set was overlaid by grasslands to erase the non-grassland fire events. The
152	occurrence counts and coordinates were saved in an attribute table. Then, all the active grassland
153	fires were compounded into one layer.

154 The standard map of the study area in the digital format and grassland fire data obtained from

155 MODIS were all set to the scale of 1:100,000 and the Transverse Mercator projection with

156 D\_WGS\_1984 datum.

157

158	KDE Methods
158	KDE Methoa

The implementation of kernel density estimation is based on the estimation of the density at each
intersection of a grid of quadrants superimposed on the data after assigning a probability density
to each event (Levine, 2000; Seaman and Powell, 1996). The estimated density results from the
sum of the densities of all the kernels overlapping at each grid cell (Worton, 1989; Tufto et al.,
163 1996).
Kernel density estimation, a non-parametric statistical method for estimating probability densities,

has been widely used for home range estimation in wildlife ecology and for forest fire risk
assessment (Amatulli et al., 2007; Boer et al., 2009; Koutsias et al., 2014; Kuter et al., 2011).

167 The bivariate kernel density estimator was mathematically defined by Silverman as follows168 (1998):

169 
$$\hat{f}(x) = \frac{1}{nh^2} \sum_{i=1}^n K \frac{1}{h} (x - X_i)$$
(1)

where n is the number of points, h is the smoothing parameter or the bandwidth, K is a kernel
density function, x is a vector of coordinates that represent the location where the function is
estimated, and X<sub>i</sub> represents vectors of coordinates that define each observation.

The kernel function can be selected from a variety of functions (De La Riva et al., 2004). In this
study, the Epanechnikov kernel function was selected, which is the default in ArcGIS. This
function is defined by Silverman as follows (1998).

176 
$$K_{e}(x) = \begin{cases} \frac{1}{2}C_{d}^{-1}(d+2)(1-x^{T}x) & if: x^{T}x < 1\\ 0 & otherwise \end{cases}$$
(2)

The bandwidth influences the smoothness of the density function by controlling the size of the kernel and the interpolation results. A narrow bandwidth generates a finer mesh density, and a larger bandwidth produces a smoother density distribution (Amatulli et al., 2007). Several methods can be used to find the appropriate size of the bandwidth (Worton, 1989; De La Riva et al., 2004).

182 To avoid the different effects of the active fire points over the areas with different degrees of 183 concentration, the mean random distance (RDmean) of an equal number of randomly distributed 184 points over an area should be considered (Koutsias et al., 2004). RDmean refers to the distribution 185 of the total number of points in a specific area. If the number of points is large, a small bandwidth 186 would be more suitable, avoiding loss of variability in the estimates. For a small number of points, 187 a large bandwidth should be adopted to avoid density estimations associated with nothing more 188 than random variability (Koutsias et al., 2004). In the present study, the RDmean method was 189 selected for the kernel bandwidth calculation. It can be based on a local or global approach. In the 190 local approach, the mean compartment area size and mean number of active fire points per 191 compartment are taken into account, whereas total size of the study area and total number of 192 active fire points are considered in the global approach. The RDmean function is defined as 193 follows (De La Riva et al., 2004):

194 
$$RDmean = \frac{1}{2}\sqrt{\frac{A}{N}}$$
(3)

where A is mean polygon size and N is mean number of active fire points inside a compartment inthe local approach. In the global approach, A is the total area of the study area and N is the total

197 number of points in the study area.

198	The double of the RDmean value was recommended as the bandwidth value in previous studies
199	(Koutsias et al., 2004; De La Riva et al., 2004). Therefore, the KDE maps of active grassland fires
200	were generated seasonally and in three periods (2001-2005, 2006-2010, 2011-2014) using values
201	of twice the RDmean.
202	
203	Accuracy assessment
204	The Monthly Tiled 500 m Burned Area Product (MCD45A1) in the study area from 2001 to 2014
205	was downloaded from the website ( <u>https://reverb.echo.nasa.gov/</u> ). The pixels with values
206	corresponding to the approximate Julian day of the burning were considered burned areas, and all
207	other codes were indicated as non-burned (Boschetti et al., 2013). The pixel values were set to one
208	for burned cells and zero for non-burned cells. The monthly burned area data sets were masked by
209	grassland data. According to the Julian day value, the masked data sets were overlaid using map
210	algebra and compiled into three periods (2001-2005, 2006-2010, and 2011-2014) and seasonal
211	data sets (spring (Julian day 334-60), summer (Julian day 61-151), autumn (Julian day 152-242)
212	and winter (Julian day 243-333)). Then, the pixel values reflected the burn times of each grid in
213	corresponding periods.
214	To characterize the sensitivity of the KDE results for grassland fires, the pixels in burned areas
215	and the same number of pixels from non-burned areas in each period were randomly selected. The
216	corresponding pixels of KDE results were also selected. All values of selected pixels were
217	inputted into SPSS software (ver. 14), and Pearson correlation coefficients in each period were
218	provided to assess the sensitivity of the KDE application to grassland fires.

219	
220	Mapping of grassland fire risk zones
221	In the study area, the KDE mapping of active grassland fires was carried out to analyse the
222	characteristics of the fire distribution. To assess the differences in fire regimes between counties
223	for supporting decision making and fire prevention policies, each county in the study area was
224	considered a compartment, and the mean density value in each compartment was generated based
225	on the kernel density surfaces. Furthermore, fire risk zones were generated with five categories
226	(very high, high, moderate, low and very low) using the mean density value in each compartment
227	based on the criterion of the "quantile" method. ArcGIS (ver. 10.2) was used to implement the
228	KDE method and produce maps.
229	
230	Results
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The double of the RDmean value was used as the bandwidth value in the KDE calculations. The parameters used in bandwidth calculations and bandwidth values are given in Table 3. For the mean random distance approach, the bandwidth was calculated using local and global mean random distance calculations and both approaches yielded the same bandwidth value of 8686 m. Using the final bandwidth value, seasonal and annual KDE maps were obtained.

246 According to the seasonal KDE maps, grassland fire points show different spatial and temporal 247 clustering patterns (Figure 4). In the spring, the spatial distribution of grassland fires is clustered 248 significantly compared to those in other seasons. The largest proportion of grassland fires occurred 249 in spring, with a percentage of 59.53%, out of all the active fire events. In descending order, the 250 other proportions are autumn (30.52%), summer (7.84%) and winter (2.11%). The largest occurrence densities of grassland fires in each season are 0.358 times/km<sup>2</sup>, 0.248 times/km<sup>2</sup>, 0.129 251 252 times/km<sup>2</sup> and 0.049 times/km<sup>2</sup>. The high-density areas are located in the northern part of the 253 study area, especially in the northeast part.

254 Three periods: 2001-2005, 2006-2010 and 2011-2014 were separately summarized and analysed. 255 The percentages of fire events in the three periods are respectively 35.3%, 31.76% and 32.71%. 256 There are no significant differences between the numbers of grassland fire events. KDE maps 257 generated for these periods are shown in Figure 5. It can be seen that there is a gradual decrease in 258 active fire events after 2005, but the trend reversed after 2010. The spatial distributions of 259 grassland fire events are similar in these three periods. Grassland fire events were dense in the 260 north and the northeast parts of the study area. In the southern part, the density was significantly 261 lower, with the density in 2006-2010 being the lowest.

Table 4 shows the results of the statistical comparison between the burned and non-burned pixel

263	values and the corresponding values of grassland fire KDE maps in each period. Based on a
264	Pearson Correlation test, the results are statistically significant. It shows that the burned areas have
265	significant positive correlations with the kernel density surfaces. The results confirm the validity
266	and sensitivity of the KDE method for application in grassland fire studies.
267	The kernel density surface was generated over the whole period (2001-2014), and each
268	compartment in the study area was reclassified into five classes according to the mean density
269	value to create zones of grassland fire occurrence (Figure 6). The reclassification of the mean

271 was labelled as very high, high, moderate, low and very low. The percentage of the total study area

density value was again based on the "quantile" method in each zone. From high to low, each zone

covered by each fire occurrence risk zone is as follows: very high, 31.66%; high, 15.07%;

moderate, 13.47%; low, 23.2%; and very low, 16.60%. Notably, over 46% of the east Inner

274 Mongolia grassland falls within a high fire risk zone.

275

270

276 Conclusions

277 Fire management departments make operational strategies for supressing, preventing and 278 forecasting grassland fires. Currently, the northwest part of the study area, the Hulunbeir 279 Grassland, is the top priority in the strategy of preventing grassland fires because it is a large and 280 continuous grassland. The administrative management in this region focuses on preventing fire 281 occurrence and reducing losses associated with grassland fires (Liu, 2016). According to our 282 results (Figures 4 and 5), the Hulunbeir grassland has nearly the lowest fire density. However, the 283 high fire risk zones with small and fragmented grassland patches are not areas where the 284 management activities focus on because the fires would result in less human and economic losses.

285 To analyse the grassland fire risk and take effective measures, fire risk zone mapping with the 286 KDM method might provide a strategic operational advantage for proper development of decision 287 support systems. 288 Although the active fire data of MODIS MOD14A1 and MYD14A1 products contain x- and 289 y-coordinates of fire events, they are in the point format and thus different from continuous areal 290 data that express anthropogenic, topographic and climatic conditions. As a nonparametric method 291 for obtaining continuous surfaces from point observations, KDE has been widely used to convert 292 historical fire data into forest fire density maps. 293 In this study, grassland fire risk zones were produced using historical grassland fire occurrence 294 data from MODIS from 2001 to 2014 based on the KDE method. When preparing KDE maps of 295 grassland fires, the mean random distance method for the calculation of bandwidth was used based 296 on the mean compartment size and mean number of active fire events per polygon, as well as the 297 global area and total active number of fire events. The seasonal and yearly KDE maps present the 298 same spatial distribution patterns. In the spring and autumn seasons and in the north and northeast 299 parts of the study area where the fire risk is high, prevention and safety measures should be 300 strengthened. 301 This paper develops a method of mapping fire risk based on historical data. It demonstrates that 302 grassland fire density mapping by KDE together with the MODIS active fire products has the 303 potential to assist grassland fire management agencies in developing appropriate management 304 strategies in areas that are more prone to fire hazard. 305

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310	
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- 436

438



Class	Meaning
0	Not processed (missing input data)
2	Not processed (other reason)
3	Water
4	Clouds
5	Non-fire clear land
6	Unknown
7	Low-confidence fire
8	Nominal-confidence fire
9	High-confidence fire
	0

#### Table 1: MOD14/MYD14 fire mask pixel classes

452

453

Table 2: The number of grassland fire events by year and month

Voor	Month									Tatal	Percent			
rear	1	2	3	4	5	6	7	8	9	10	11	12	Total	(%)
2001	0	0	59	104	13	4	1	3	51	4	14	0	253	4.20
2002	0	18	58	21	12	13	6	41	44	28	63	0	304	5.05
2003	0	18	287	127	350	51	5	3	6	4	1	0	852	14.15
2004	0	5	10	56	6	24	14	33	10	31	7	2	198	3.29
2005	1	1	87	96	18	19	3	33	169	99	6	0	532	8.84
2006	0	1	22	118	128	10	2	6	121	16	1	1	426	7.08
2007	1	27	18	144	18	7	6	42	61	7	0	8	339	5.63
2008	0	18	279	83	21	7	1	7	29	9	22	3	479	7.96
2009	0	4	8	126	70	1	2	2	46	60	21	0	340	5.65
2010	0	3	5	62	41	14	5	12	70	100	16	0	328	5.45
2011	0	3	19	228	11	8	2	17	44	37	9	0	378	6.28
2012	0	3	79	131	43	6	2	17	28	13	12	0	334	5.55
2013	0	0	1	99	135	6	8	4	103	105	42	1	504	8.37
2014	2	6	155	221	15	9	6	10	223	88	18	0	753	12.51
Total	4	107	1,087	1,616	881	179	63	230	1,005	601	232	15	6,020	100.00
Percent	0.07	1.78	18.06	26.84	14.63	2.97	1.05	3.82	16.69	9.98	3.85	0.25	100.00	

454									
455									
456									
457	Table 3	Table 3: Parameters related to bandwidth calculations							
	Total size of the	study area, A	454,204.51 km <sup>2</sup>						
	Total number of	fpolygons	36						
	Total number of	factive fire events, N	6,020						
	Mean polygon s	Mean polygon size							
	Mean number o	f active fire events per poly	gon 167.22						
	Local RDmean		8,686.21 m						
	Global RDmear	1	8,686.15 m						
458		Q,							
459									
460									
461	Table 4: The Pearson Correlat	ion Coefficients for the burn	ned and non-burned area pixel values and						
462	the corresponding	pixel values of grassland f	ire KDE maps in each period						
	Pixel values of		Pixel values of burned and						
	KDE maps		non-burned areas						
	2001-2005	Pearson Correlation	.470**						
		Sig. (2-tailed)	.000						
		Ν	10,336						
	2006-2010	Pearson Correlation	.613**						

	Sig. (2-tailed)	.000
	Ν	3,600
2011-2014	Pearson Correlation	.469**
	Sig. (2-tailed)	.000
	Ν	4,988
Spring	Pearson Correlation	.489**
	Sig. (2-tailed)	.000
	Ν	13,114
Summer	Pearson Correlation	.317**
	Sig. (2-tailed)	.000
	Ν	697
Autumn	Pearson Correlation	.433**
	Sig. (2-tailed)	.000
	Ν	4,192
Winter	Pearson Correlation	.539**
	Sig. (2-tailed)	.000
	Ν	166

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- 470 Figure 1: The location of the study area in the east Inner Mongolia Autonomous Region of China
- 471 Figure 2: Distribution of grassland fire events from 2001 to 2014 observed by MODIS
- 472 Figure 3: Monthly time series of grassland active fire events
- 473 Figure 4: The KDE maps in different seasons: (a) spring, (b) summer, (c) autumn and (d) winter
- 474 Figure 5: The KDE maps of different periods from 2001-2005, 2006-2010 and 2011-2014
- Figure 6: The KDE map of the whole study period (2001-2014) (a) and grassland fire risk map of
- 476 the study area according to the mean density value of KDE (b)
- 477



Figure 1: The location of the study area in the east Inner Mongolia Autonomous Region of China



Figure 2: Distribution of grassland active fire points from 2001 to 2014 observed by MODIS







Figure 4: The KDE maps in different seasons: (a) spring, (b) summer, (c) autumn and (d) winter



Figure 5: The KDE maps of different periods from 2001-2005, 2006-2010 and 2011-2014



Figure 6: The KDE map of the whole study period (2001-2014) (a) and grassland fire risk map of

the study area according to the mean density value of KDE (b)



Associate Editor's Comments to Author:

Associate Editor

Comments to the Author:

The revised version of the manuscript presents a considerable improvement. I still have concerns with the language of the manuscript which, although grammatically correct, frequently reads awkwardly. I would strongly urge the authors to get in touch with a professional language editing service to have native speakers edit the manuscript. I believe the paper warrants publication despite the recommendation for rejection from one of the anonymous reviewers. However, I would recommend a subsequent minor revision following the comments from the reviewers and some very minor comments below:

L19: Imprecise rather than inaccurate positions

A: we accepted it. (Line 19)

L61: Please rephrase "During these events, some fatal accidents can occur, including losses of human lives and economic resources" to something along the lines "These events at times lead to fatal accidents and result in human life loss as well as impose burned of economic resources." It would be nice if you could elaborate what leads to those? Smoke? But if no causes are readily apparent, you could skip it.

A: flame, smoke, heat, etc. can lead to those matters. It cannot be expressed easily. So we deleted this sentence.

Line 202: Please replace "validation" with "accuracy assessment" because validation is a much more rigorous process that requires a lot more precision than using MCD54A1.

A: we accepted it. (Line 203)

Reviewers' Comments to Author:

Reviewer: 1

Comments to the Author

Revisions covered all of my comments. Please update Table 3 with commas in large numbers.

A: Commas was added in the tables. (Line 457)

Reviewer: 2

Comments to the Author

While the authors present interesting work, there is a mismatch between goals and conclusions and the conclusions are not supported by the work. The goals stated are to understand spatial patterns and demonstrate a method. The method is demonstrated, but I do not see any compelling evidence in the manuscript supporting a need for the method within the context presented. The active fire and burned area products used jointly also define spatio-temporal patterns of fire as continuous, areal maps. The conclusions take the goals one step further to say this work produced fire risk zones. Fire risk cannot be determined from past fire events alone and is more accurately described and modeled in Bian et al. 2013 in the Fire Safety Journal.

A: Fire occurrence is due to the comprehensive effect of factors, such as climate, weather, human activities, social economic, fuel mass and moisture. The location of past fire events has higher risk. The neighbors of the past fire events have the similar influencing factors. So the risk of these neighbors is also higher although the fire didn't occur at the locations because fire occurrence has some uncertainty and random. During the period of our study (from 2001 to 2014), the variations of the influencing factors are not very large. So the density derived from the past fire events can express the risk of fire occurrence and the fire risk zone can be used to present the distribution of fire risk.

Fire risk also can be described and modeled by the previous methods. And these methods can not only show the quantitative relationship between the risk and the factors, but also the distribution of fire risk. Even more, the continuous surface of fire density has been proved that they can support the analysis of these models with the corresponding factors.

So, the spatial-temporal patterns of fire distribution can be express by the produced fire risk zones.

In addition, I see some problems with the groupings used for analysis. First, the year ranges given (2001-2005, 2006-2010, 2011-2014) are not three-year periods.

A: the words were changed to "three periods". (Line 210)

Second, the seasonality assessment doesn't make sense since the seasons are defined in the manuscript as quartiles of the annual Julian calendar starting at 1 instead of by climatological indicators.

A: our carelessness led to this mistake. The seasons we used in this study were defined according to climatological indicators (it can be found in the sentences (lines

245-250) compared with table 2). Because the data of MCD45A1 was organized by Julian day, the seasons were compiled according to Julian day too.

In the revised manuscript, the mistake was corrected as follows: spring (Julian day 334-60), summer (Julian day 61-151), autumn (Julian day 152-242) and winter (Julian day 243-333). (Lines 211-212)

While the manuscript has been improved in terms of English language, there still exist some awkward and unclear portions that need additional attention. I strongly encourage editing by a professional service.

A: The manuscript has been improved again by an English speaker. If it need edit again, please notice us.

Finally, please include line numbers in your responses so that reviewers may find your edits more easily.

A: the line numbers were added.