

Supplementary Materials

Biomass Burning in Northeast China over Two Decades: Temporal Trends and Geographic Patterns

Heng Huang ¹, Yinbao Jin ^{2,†}, Wei Sun ^{1,*}, Yang Gao ³, Peilun Sun ¹, Wei Ding ¹

¹ School of Geomatics, Liaoning Technical University, Fuxin 123000, China; huangheng@lntu.edu.cn

² School of Atmospheric Sciences, Sun Yat-Sen University, Zhuhai 519082, China; jinyb3@mail2.sysu.edu.cn

³ Department of Geomatics Engineering, University of Calgary, Calgary, AB T2N 1N4, Canada; ygao@ucalgary.ca

* Correspondence: sunwei@lntu.edu.cn

† These authors contributed equally to this work

Tables

Table S1. The correspondence between the International Geosphere-Biosphere Programme (IGBP) classification and the land-cover categories of biomass burning (BB) in this study.

No.	Forest	Cropland	Urban	Others
1	Evergreen Needleleaf forest	Croplands	Urban and Built-up Lands	Permanent Wetlands
2	Evergreen Broadleaf forest	Cropland/Natural vegetation mosaic		Permanent Snow and Ice
3	Deciduous Needleleaf forest			Barren
4	Deciduous Broadleaf forest			Water Bodies
5	Mixed forest			Unclassified
6	Closed shrublands			
7	Open shrublands			
8	Woody savannas			
9	Savannas			
10	Grasslands			

Table S2. Five trend categories.

Slope	Slope assignment	z	p	z or p assignment	Trend value	Trend category
>0	1	>1.96	<0.05	2	2	Significant Increase
		<1.96	>=0.05	1	1	Non-significant Increase
0	0	>1.96	<0.05	2	0	Unchanged
		<1.96	>=0.05	1	0	
<0	-1	>1.96	<0.05	2	-2	Significant Decrease
		<1.96	>=0.05	1	-1	Non-significant Decrease

Table S3 Population statistics of Songnen plain (SNP) and Sanjiang plain (SJP) from 2017 to 2020.

Year	SNP (Million people)									SJP (Million people)						
	Harbin	Qiqihar	Daqing	Heihe	Suihua	Changchun	Songyuan	Baicheng	Total	Jixi	Hegang	Shuangyashan	Yichun	Jiamusi	Qitaihe	Total
2019	9.51	5.27	2.75	1.58	5.22	7.54	2.75	1.89	36.49	1.69	0.99	1.41	1.12	2.32	0.77	8.30
2020	10.00	4.04	2.78	1.28	3.72	8.53	2.73	1.86	34.94	1.49	0.89	1.20	0.87	2.15	0.69	7.29
2021	9.43	5.17	2.72	1.54	5.13	8.52	2.72	1.85	37.06	1.65	0.96	1.37	1.08	2.28	0.75	8.09
2022	9.82	3.94	2.73	1.25	3.63	8.51	2.71	1.83	34.42	1.45	0.86	1.17	0.84	2.10	0.67	7.09

* The data is sourced from the Heilongjiang Statistical Yearbook and the Jilin Statistical Yearbook, the statistics of Songnen plain (SNP) and Sanjiang plain (SJP) are accurate to the city level.

Table S4. Recent policies on straw burning management and comprehensive utilization in the northeast China (NEC).

Province	Date	Name	Main Content
Liaoning	2015/07/20	Notice on the Implementation of Straw Burning Ban in 2015	Implement responsibilities and strengthen inspection and supervision
	2016/01/14	Implementation Opinions on Promoting Comprehensive Utilization and Ban of Crop Straw (2016-2018)	Increase the utilization rate of straw and enhance the supervision of straw ban.
	2018/10/11	Liaoning Province Straw Burning Control and Accountability Measures	Specify the circumstances and methods of accountability for straw burning.
	2018/10/13	Three-Year Action Plan for Winning the Blue-Sky Defense Battle in Liaoning (2018-2020)	Promote straw control and ammonia emission control.
	2022/09/12	Implementation Plan for Carbon Peak in Liaoning Province	Improve the utilization level of straw and strictly regulate the prohibition of straw burning
Jilin	2016/05/27	Regulations on Air Pollution Prevention and Control in Jilin Province	Prohibit the open burning of straw in violation of relevant regulations.
	2018/08/21	Implementation Plan for Winning the Blue-Sky Defense Battle in Jilin Province	Comprehensive strengthening of straw ban and control.
	2021/09/08	Opinion on Implementing the "Straw to Meat" and Ten Million Head of Livestock Project	Utilize straw for animal feed.
	2022/08/12	Notice on Convening the Deployment Meeting for Autumn and Winter Straw Burning Ban Work in 2022 for the Province's Ecological and Environmental Departments	Arrange and deploy the nationwide ban on straw burning in autumn and winter throughout the province
Heilongjiang	2016/10/08	Notice on Issuing the Implementation Plan to Improve Air Quality by Banning Wild Straw Burning in Heilongjiang	Designate no-burning zones and increase comprehensive straw utilization.
	2018/11/17	Three-Year Action Plan for Winning the Blue-Sky Defense Battle in Heilongjiang	Strengthen comprehensive straw utilization and strictly control open-air straw burning.
	2022/09/27	Implementation Plan for Comprehensive Utilization of Straw in Heilongjiang Province in 2022	Promoting the Comprehensive Utilization of Straw Industry to Improve Quality and Efficiency.
	2023/10/26	Implementation Plan for Comprehensive Utilization of Straw in Heilongjiang Province (Provisional)	Expand the comprehensive utilization of straw and strengthen the guarantee of scientific and technological services

Sensitivity analysis of HDBSCAN algorithm

Figure S1 presents a sensitivity analysis of the minimum cluster size parameter in HDBSCAN, focusing on significant biomass burning increase (BBI) and decrease (BBD) points. The figure shows the effects of three settings—10, 15, and 20—on the clustering of BBI and BBD.

1) Minimum Cluster Size of 10: This setting results in the aggregation of noise or incidental data points into valid clusters, leading to overfitting particularly noticeable in the Liaohe Plain BBD area.

2) Minimum Cluster Size of 15: This setting provides the most balanced representation, accurately capturing the nuances of both increases and decreases in biomass burning.

3) Minimum Cluster Size of 20: Several distinct clusters are merged into larger ones, resulting in underfitting, particularly evident in the Songnen Plain BBI area.

A minimum cluster size of 15 is recommended for optimal analysis. This setting effectively balances sensitivity and specificity, avoiding the over-clustering and under-clustering issues evident at the extremes of 10 and 20, respectively.

Figures

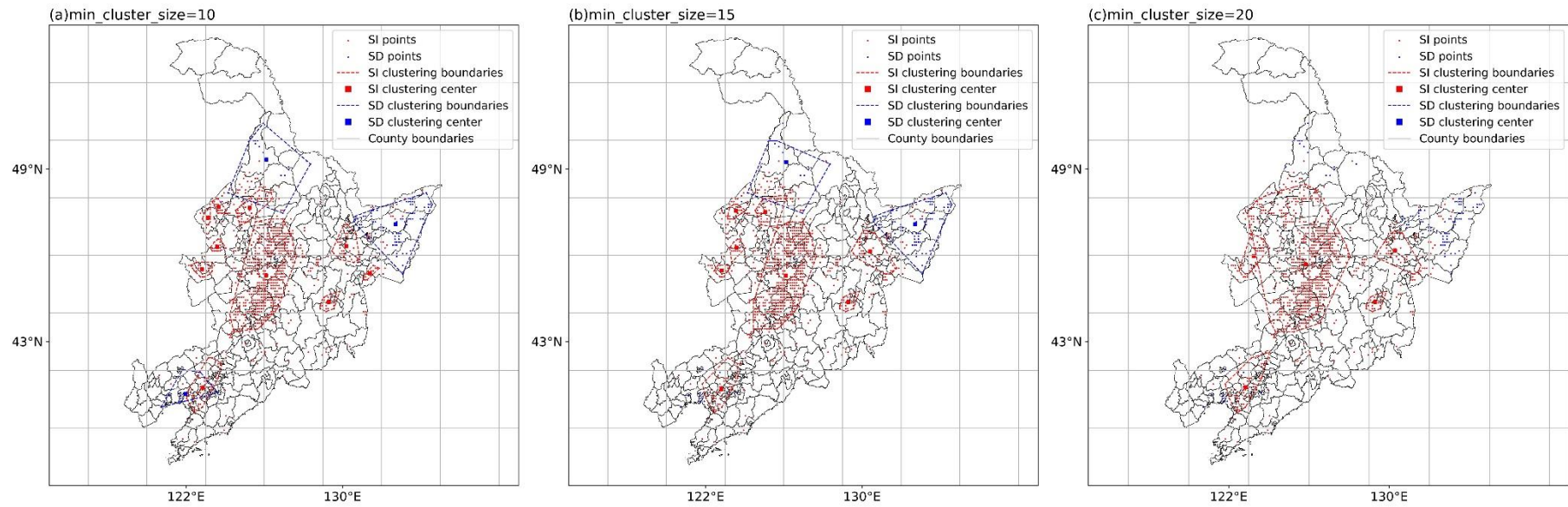


Figure S1 Sensitivity analysis of minimum cluster size in HDBSCAN for clustering biomass burning (BB) data.

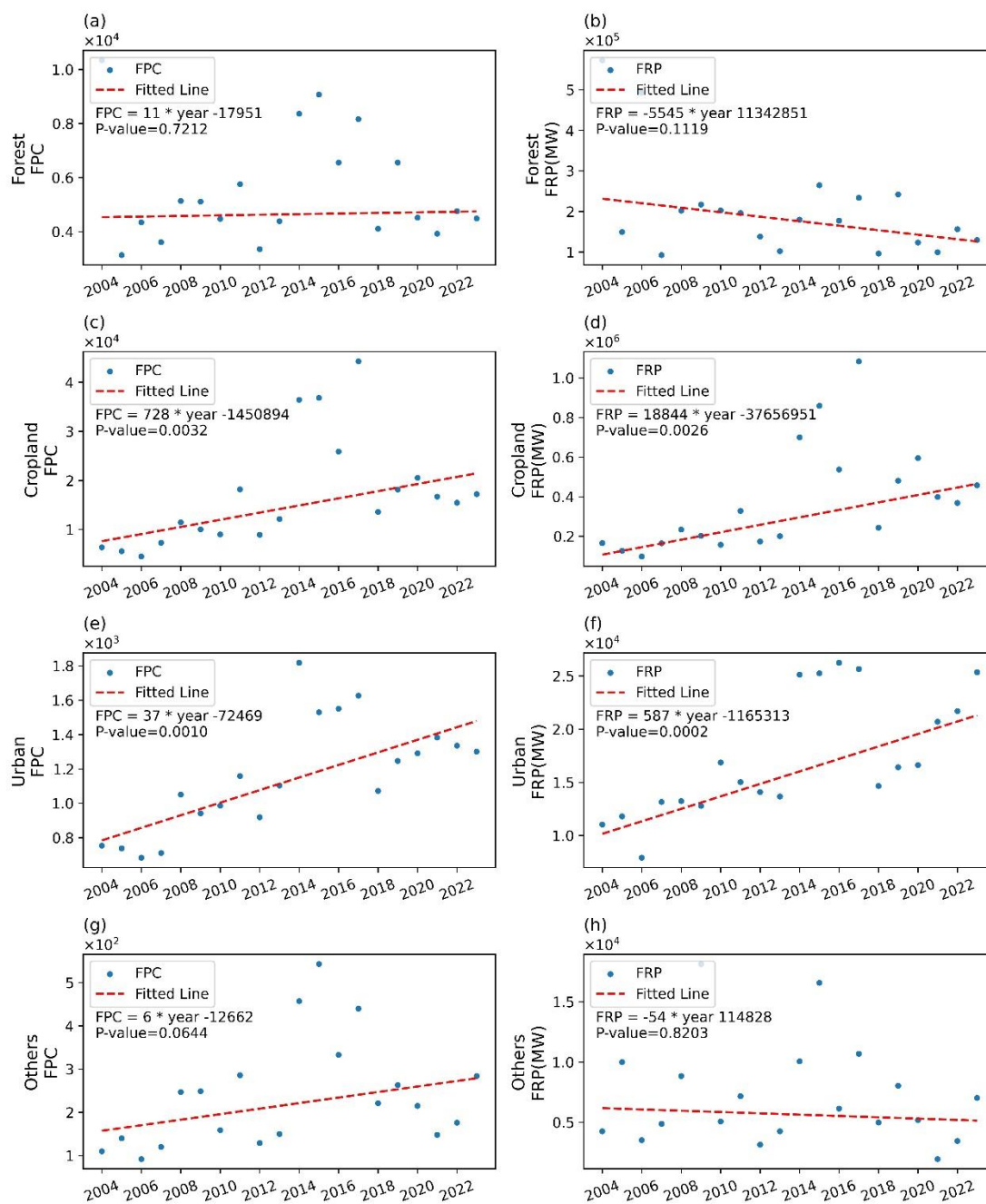


Figure S2. The Mann-Kendall (MK) trend analysis of fire pixel counts (FPC) and fire radiative power (FRP) for various land-cover types.

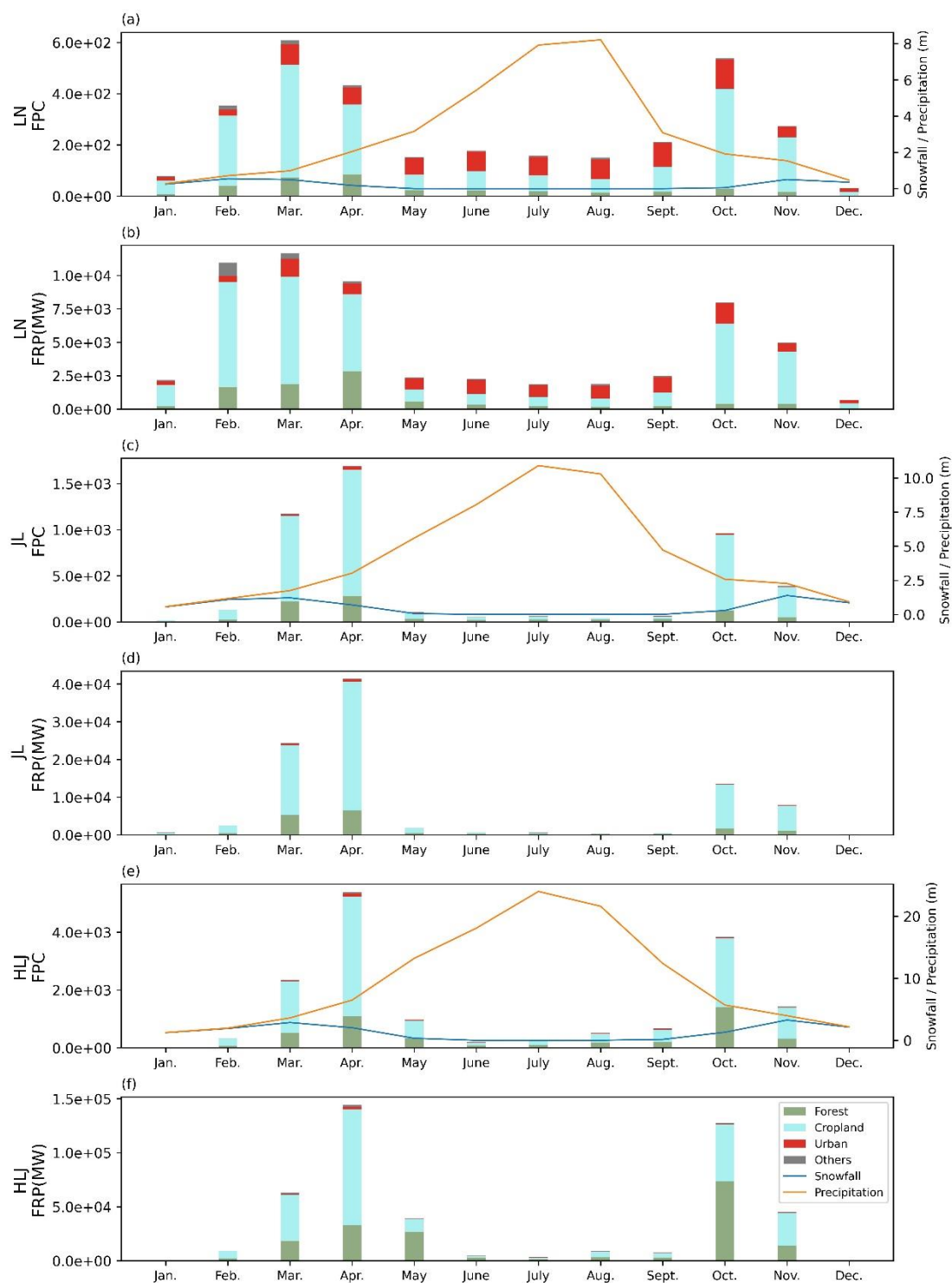


Figure S3. Monthly statistics of fire pixel counts (FPC) and fire radiative power (FRP) in (a-b) Liaoning(LN), (c-d) Jilin(JL), and (e-f) Heilongjiang(HLJ).

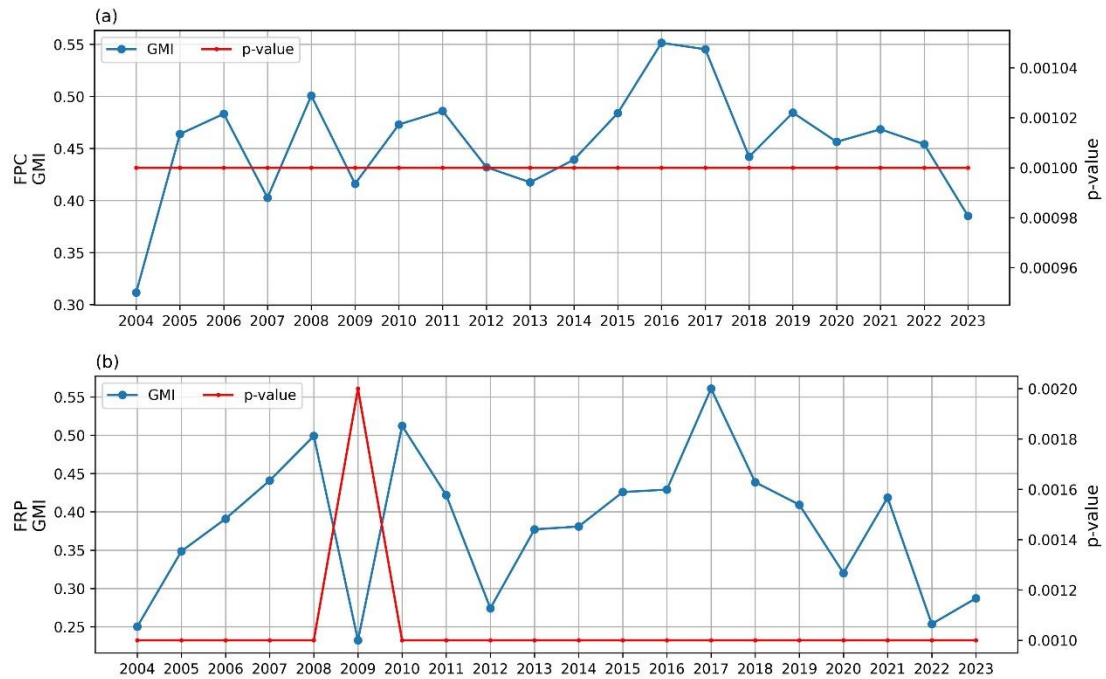


Figure S4. The GMI and its p-values for BB from 2004 to 2023, where (a) represents fire pixel counts (FPC) and (b) represents fire radiative power (FRP).

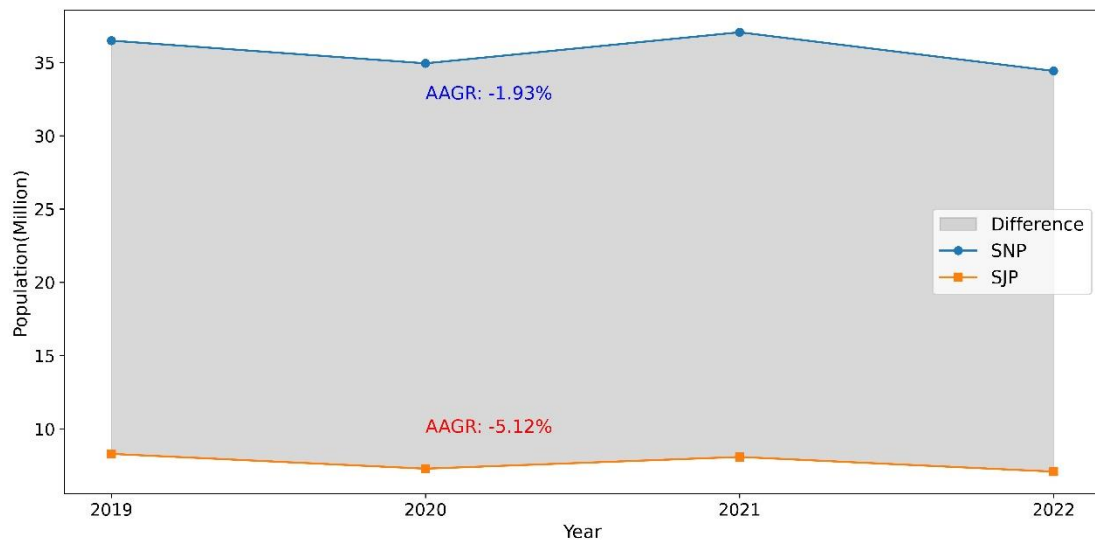


Figure S5. Trends in population and average annual growth rate (AAGR) for Songnen Plain (SNP) and Sanjiang Plain (SJP) from 2017 to 2022.

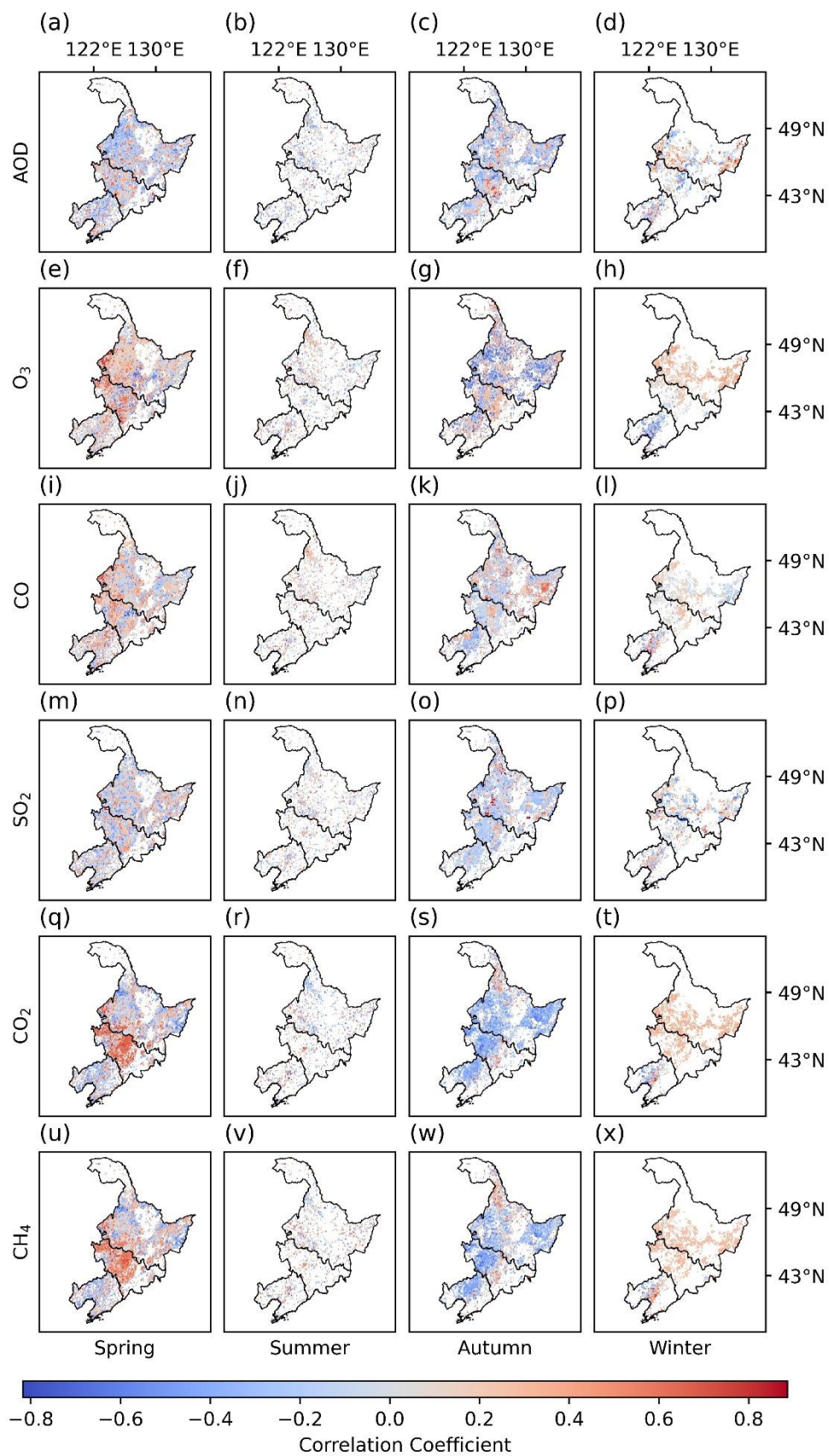
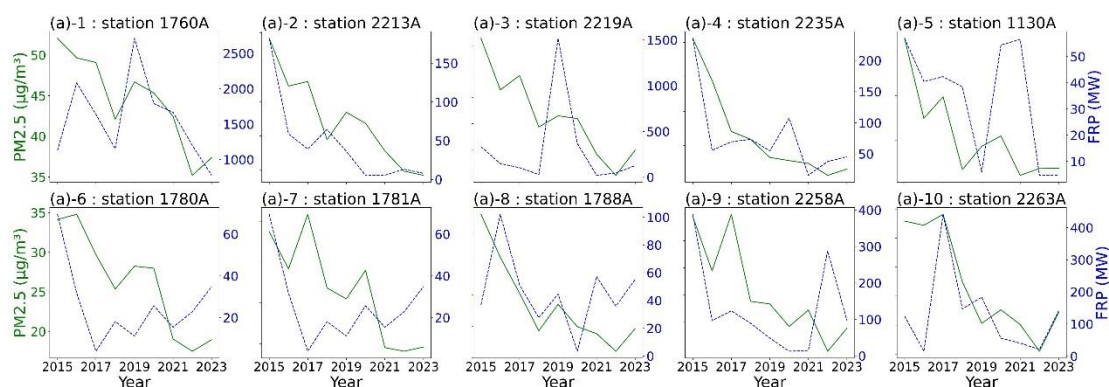
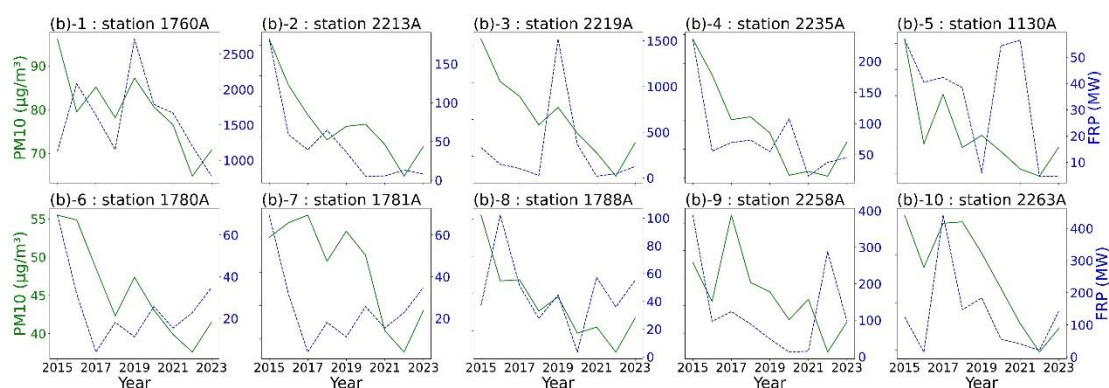


Figure S6. Spatial distribution map of correlation coefficients between biomass burning (BB) and major atmospheric pollutants across seasons.

(a) Time Series of PM_{2.5} and FRP at Various Stations(b) Time Series of PM₁₀ and FRP at Various Stations

(c) Time Series of CO and FRP at Various Stations

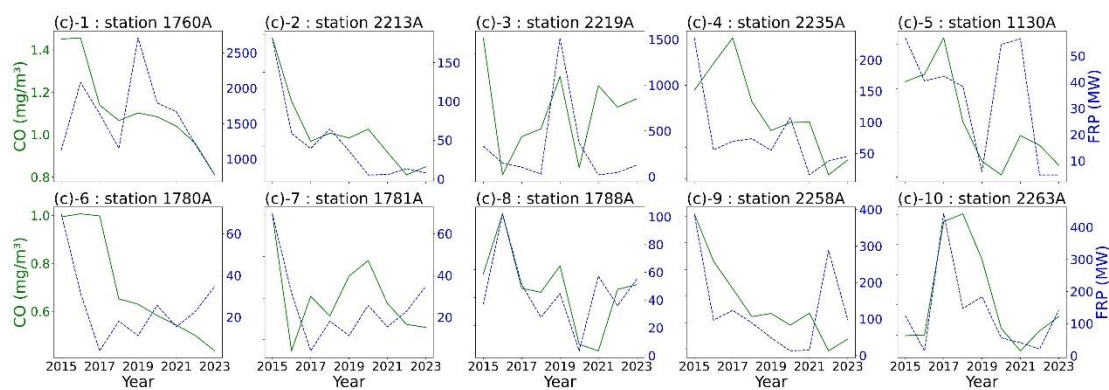


Figure S7. Temporal trends of PM_{2.5}, PM₁₀, and carbon monoxide (CO) concentrations alongside fire radiative power (FRP) at various monitoring stations from 2015 to 2023.

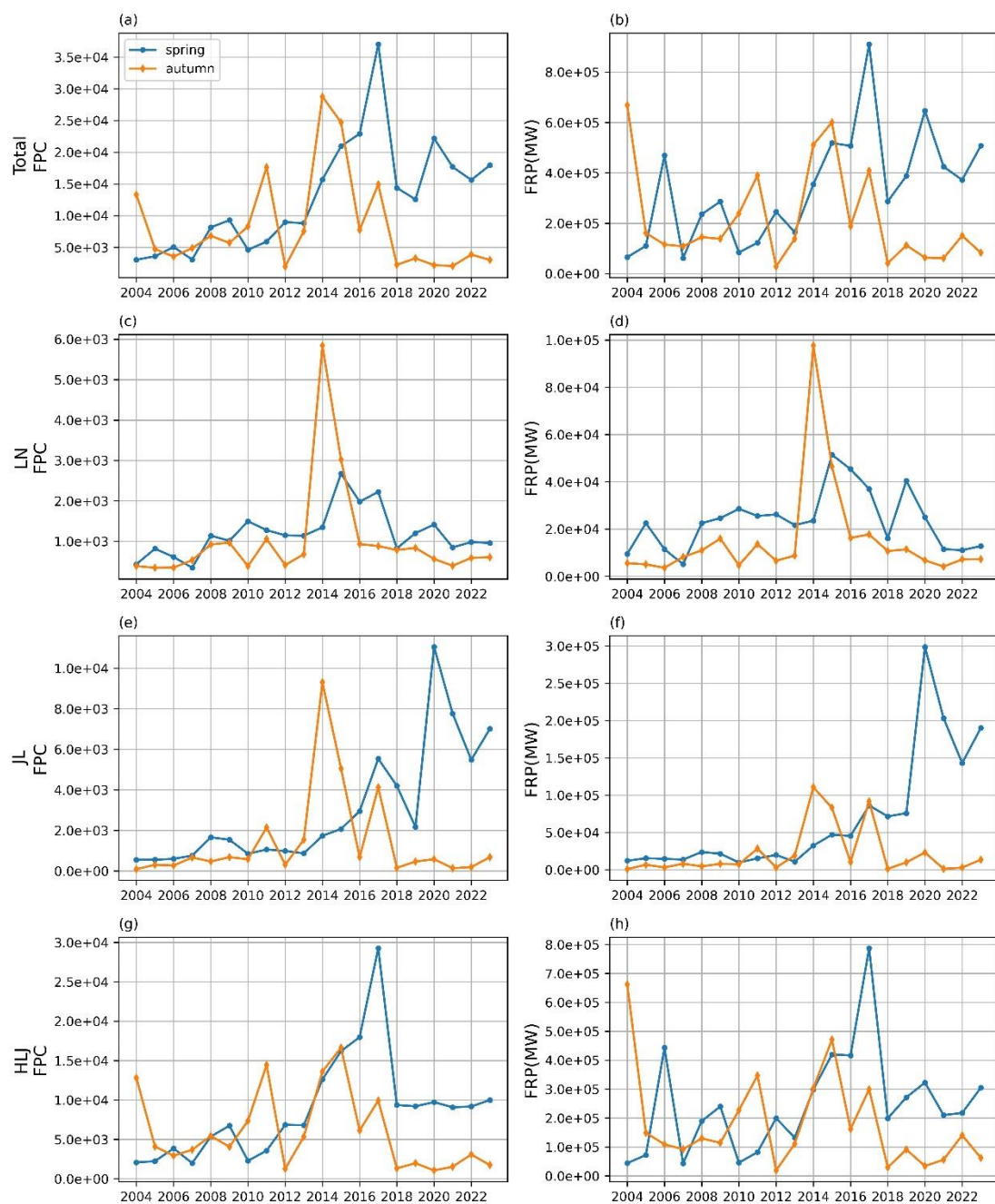


Figure S8. The comparison of fire pixel counts (FPC) and fire radiative power (FRP) between spring and autumn from 2004 to 2023.

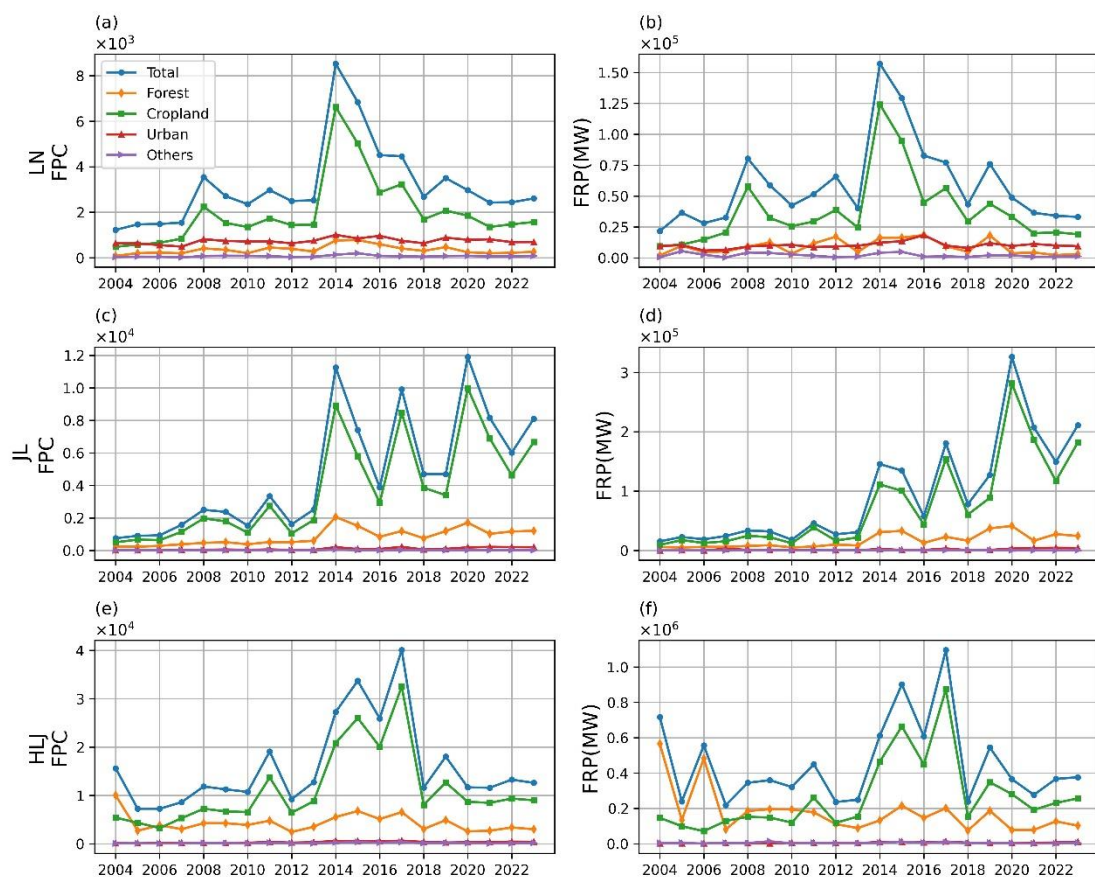


Figure S9. Line chart of fire pixel counts (FPC) (left column) and fire radiative power (FRP) (right column) for various land-cover types in (a-b) Liaoning (LN), (c-d) Jilin (JL), and (e-f) Heilongjiang (HLJ) from 2004 to 2023.