Supplementary material for:

The newly developed Multi-ensemble Biomass-burning Emissions Inventory (MBEI): Characterizing and unraveling spatiotemporal uncertainty in global biomass burning emissions

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Supplementary Figure

2 Materials and Methods

2.1 Datasets

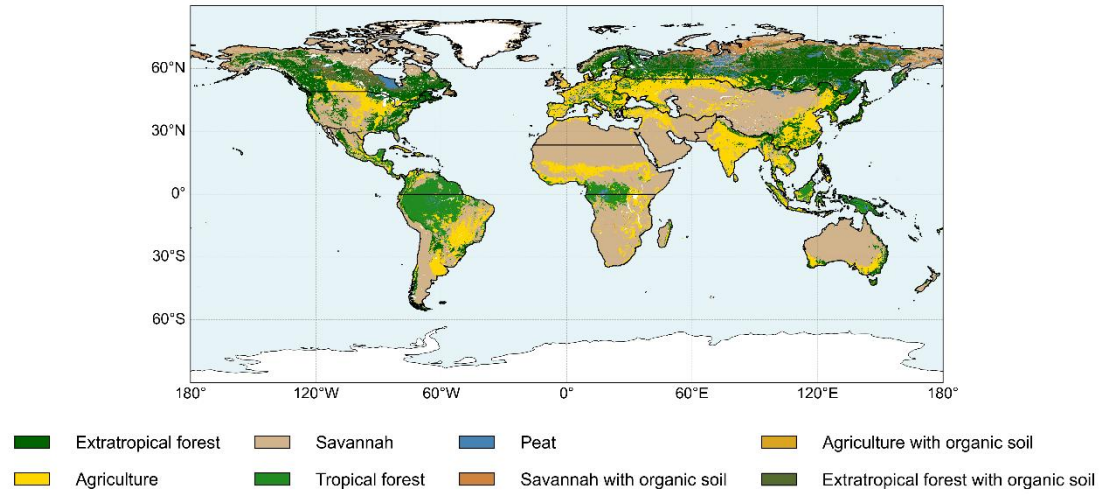

Figure S1. 8-class biomass burning region types map. Region types 1–5 are derived from merging the 30 combustion region types shown in Supplementary Figure 2. Region types 6–8 (organic soil) are based on the GLOBAL PEATLAND MAP 2.0. In this dataset, grid cells of the land-use type "peat in soil mosaic" with a coverage fraction greater than 80 % within Savannah, Agriculture, and Extratropical forest regions are classified as "Savannah with organic soil", "Agriculture with organic soil", and "Extratropical forest with organic soil", respectively.

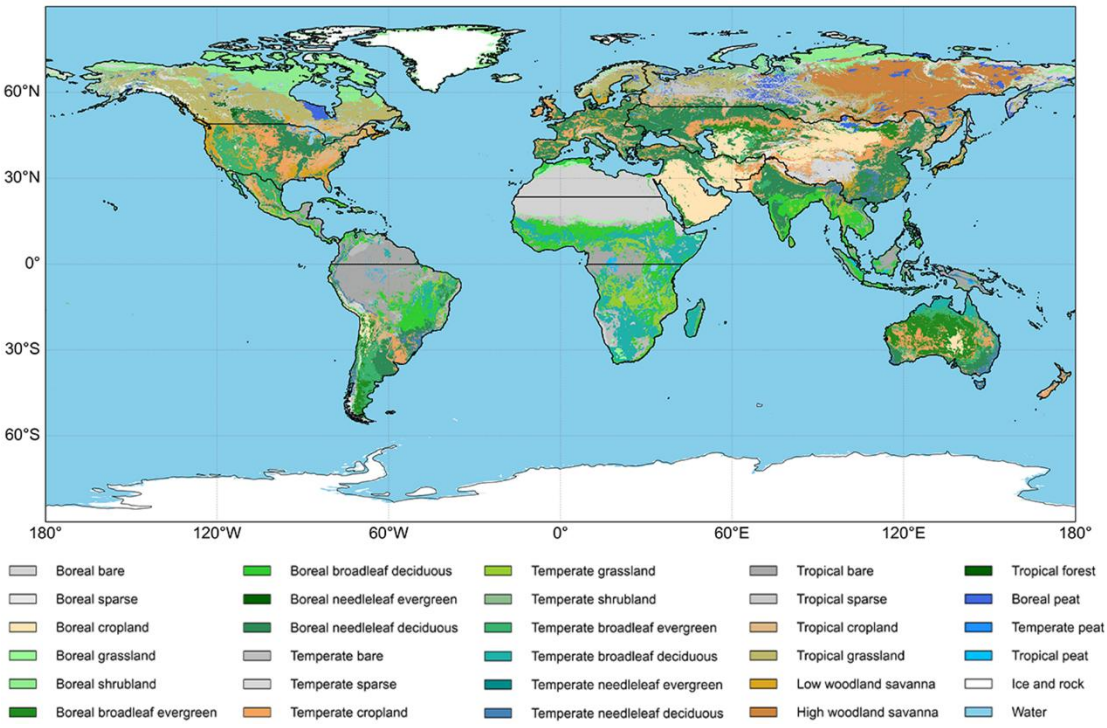

Figure S2. 30-class biomass burning region types map.

3 Result

3.1 Spatial patterns and uncertainty of global biomass burning emissions

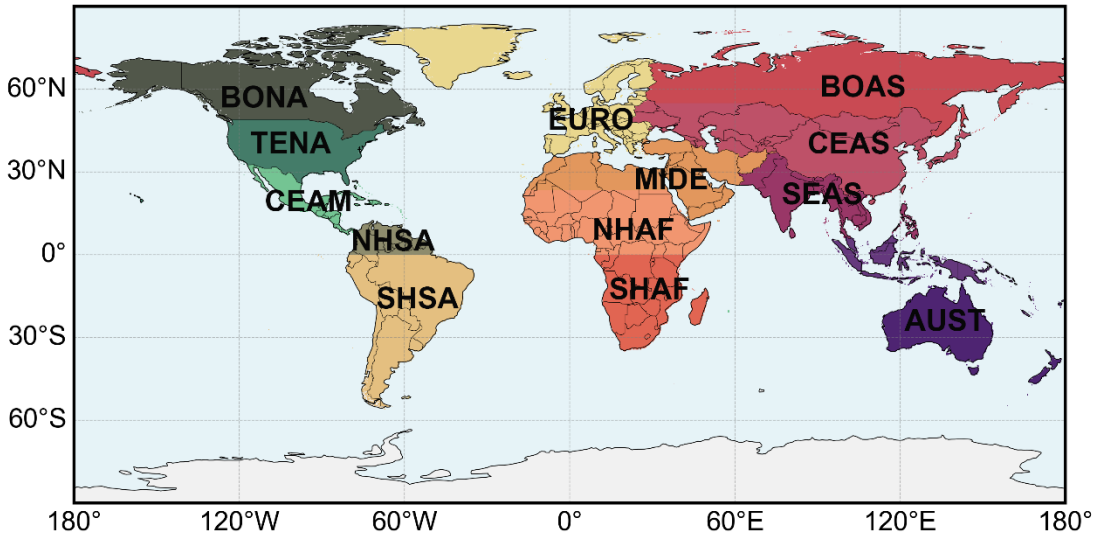

Figure S3. Global 14 regions based on GFED. BONA – Boreal North America; TENA – Temperate North America; CEAM – Central America; NHSA – Northern Hemisphere South America; SHSA – Southern Hemisphere South America; EURO – Europe; MIDE – Middle East; NHAF – Northern Hemisphere South Africa; SHAF – Southern Hemisphere South Africa; BOAS – Boreal Asia; CEAS – Central Asia; SEAS – Southeast Asia; EQAS – Equatorial Asia; AUST – Australia and New Zealand.

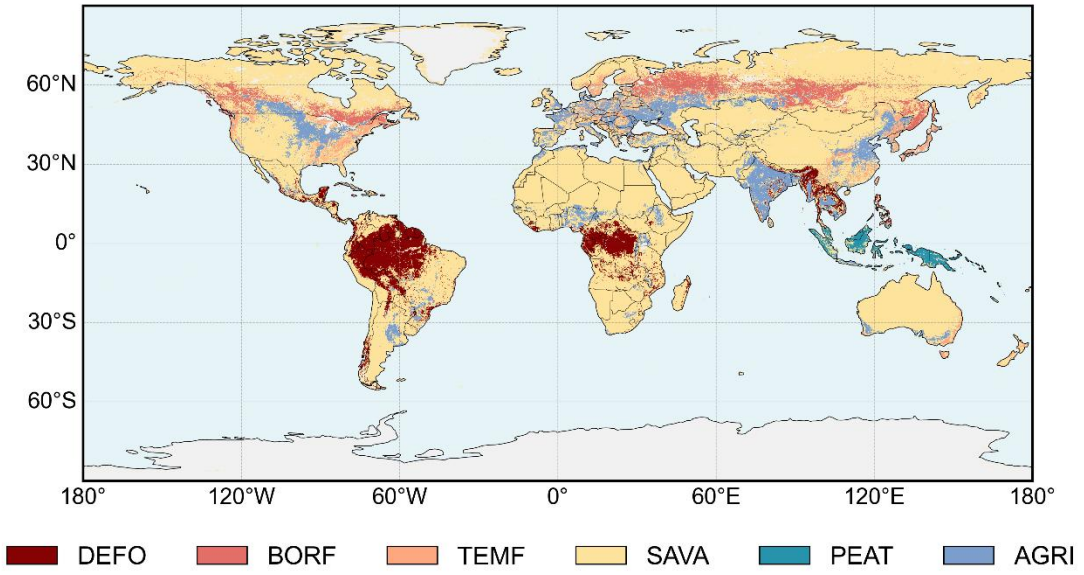

Figure S4. Global distribution of six fire types. DEFO – tropical deforestation and degradation; BORF – boreal forest fires; TEMF – temperate forest fires; SAVA – savanna, grassland, and shrubland fires; PEAT – peatland fires; AGRI – agricultural waste burning.

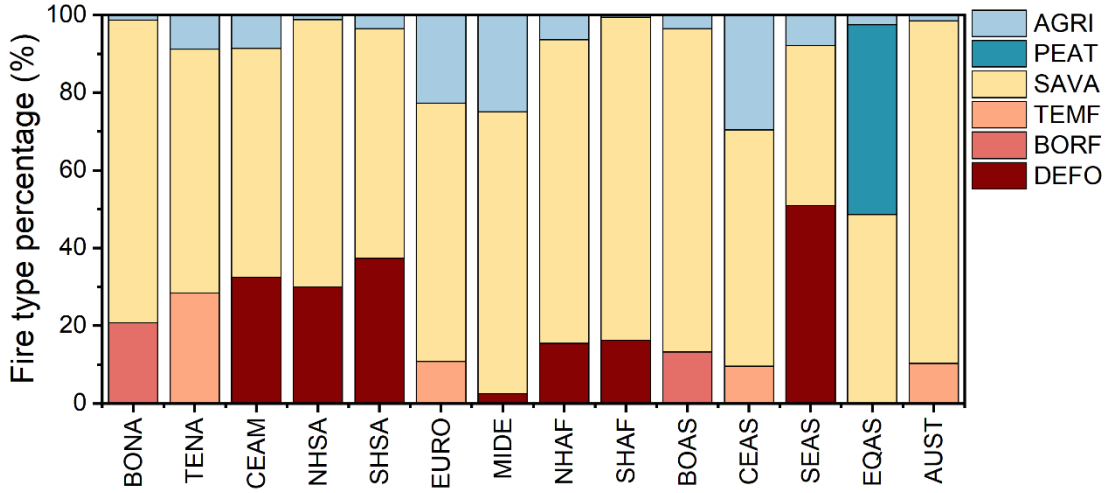

Figure S5. Proportion of fire types in 14 global regions for the multi-year period 2003–2023.

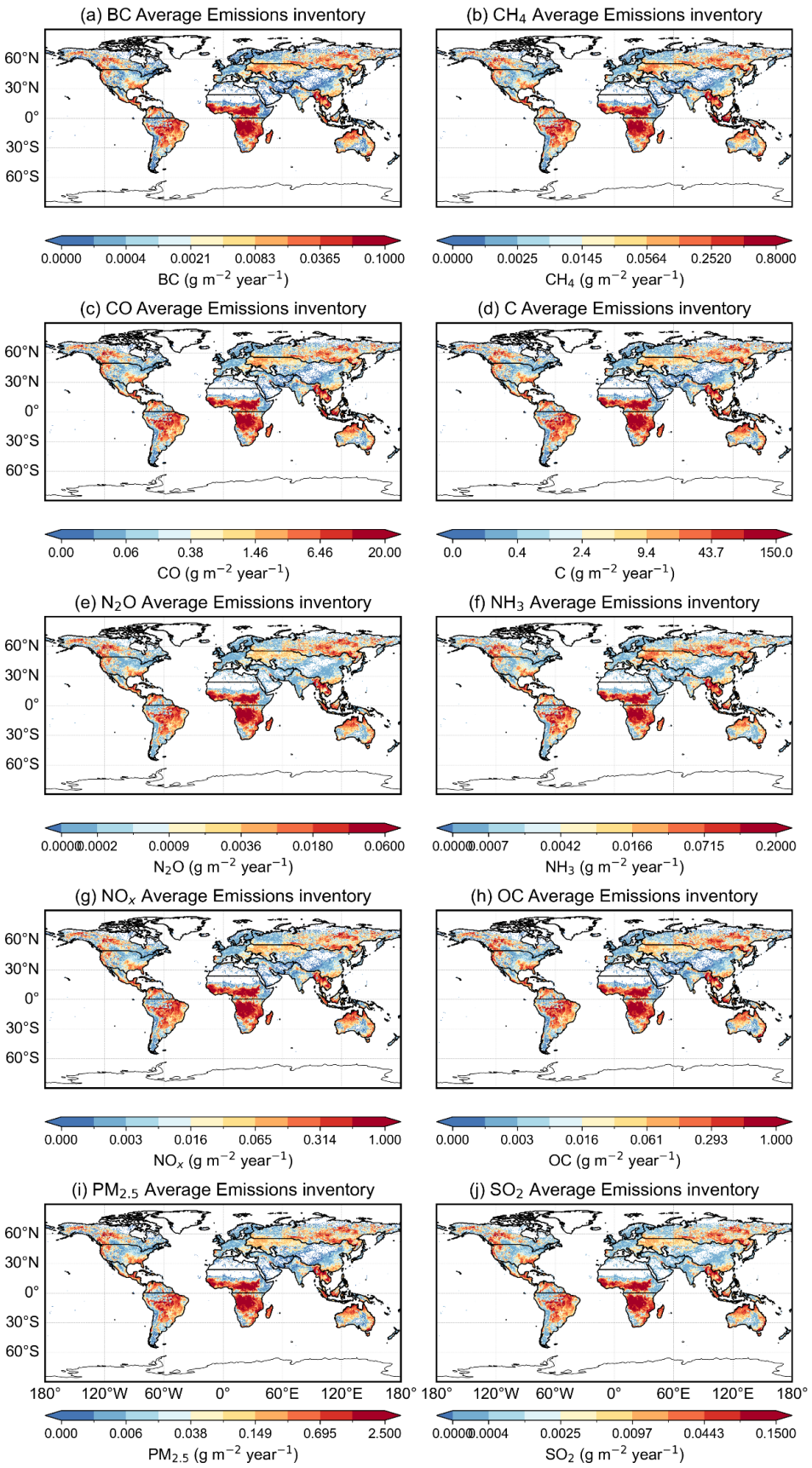

Figure S6. Multi-year mean characteristics of global biomass burning emission factors in terms of spatial patterns and regional composition (2003–2023).

3.2 Seasonality of biomass burning emissions

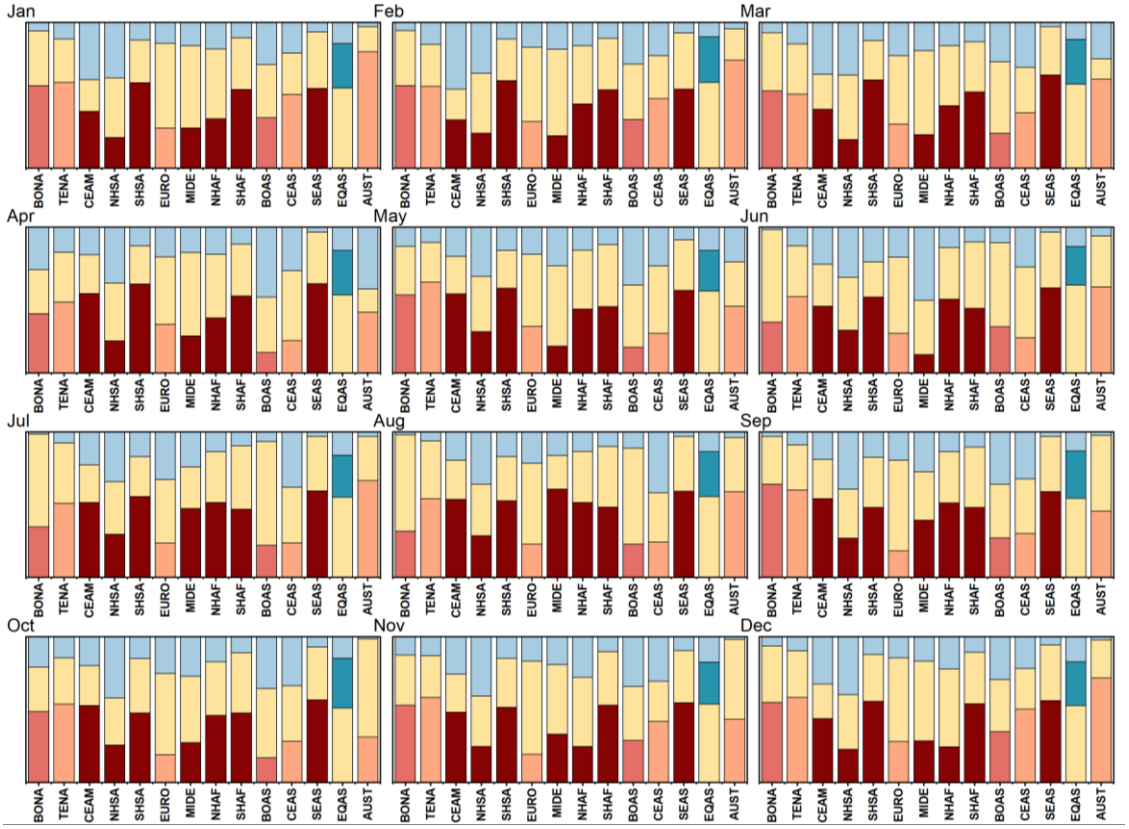

Figure S7. Monthly proportion of CO_2 emissions from six fire types in 14 global regions during 2003–2023.

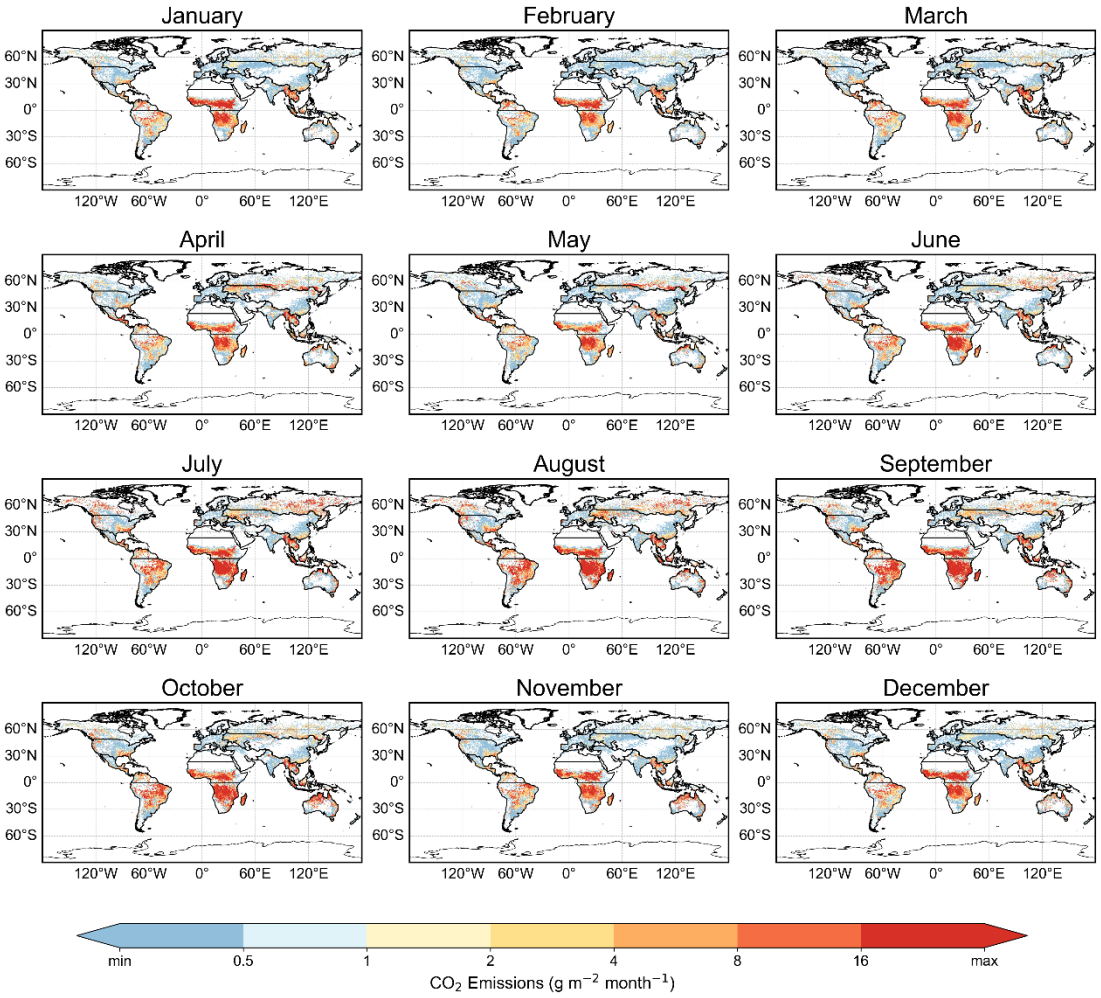

Figure S8. Spatial distribution patterns of monthly mean CO_2 emissions from biomass burning globally during 2003–2023.

3.3 Interannual variability and long-term trends

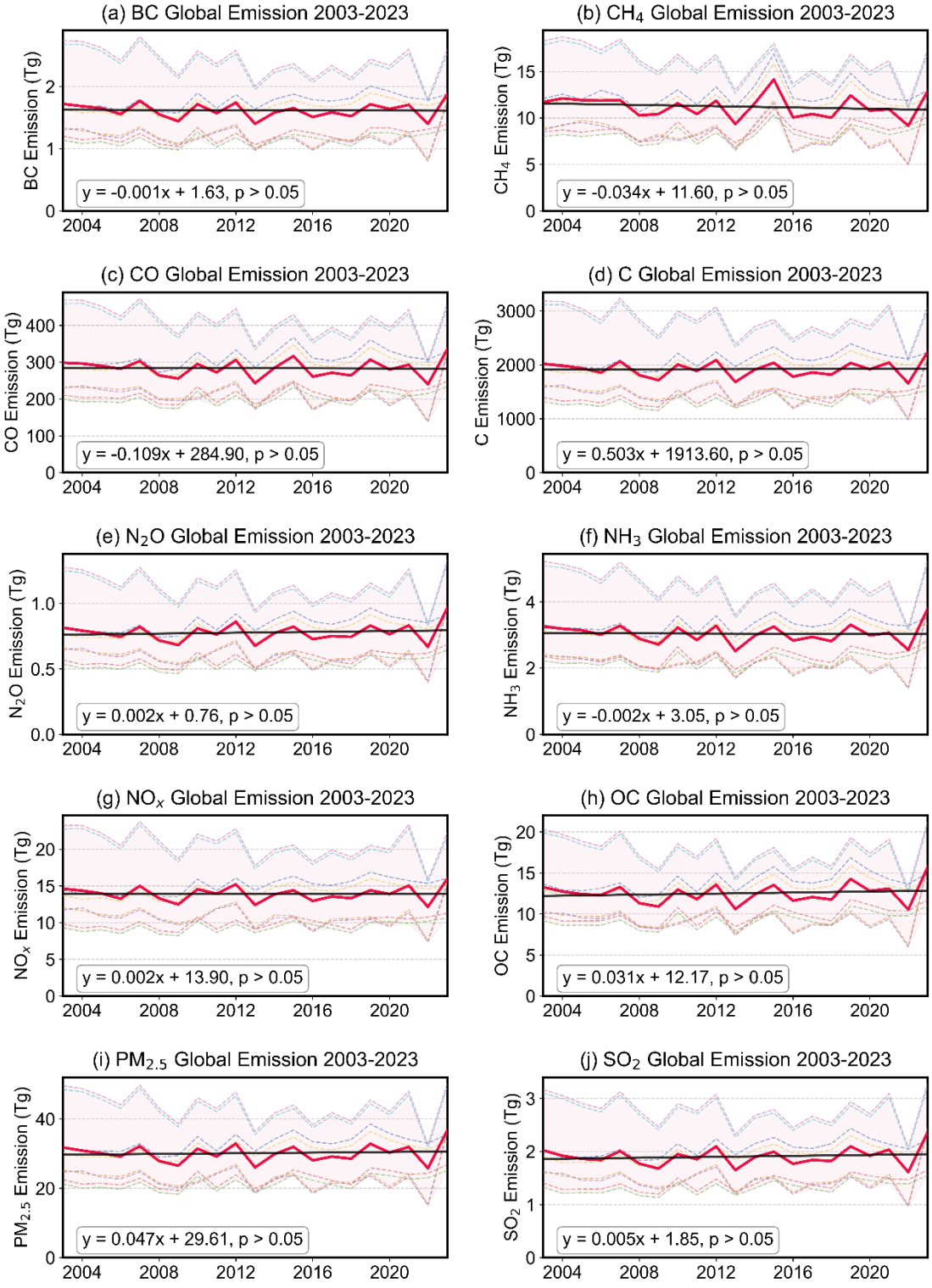

Figure S9. Annual total emissions of global biomass burning emission factors during 2003–2023.

3.4 Inter-comparison with other inventories

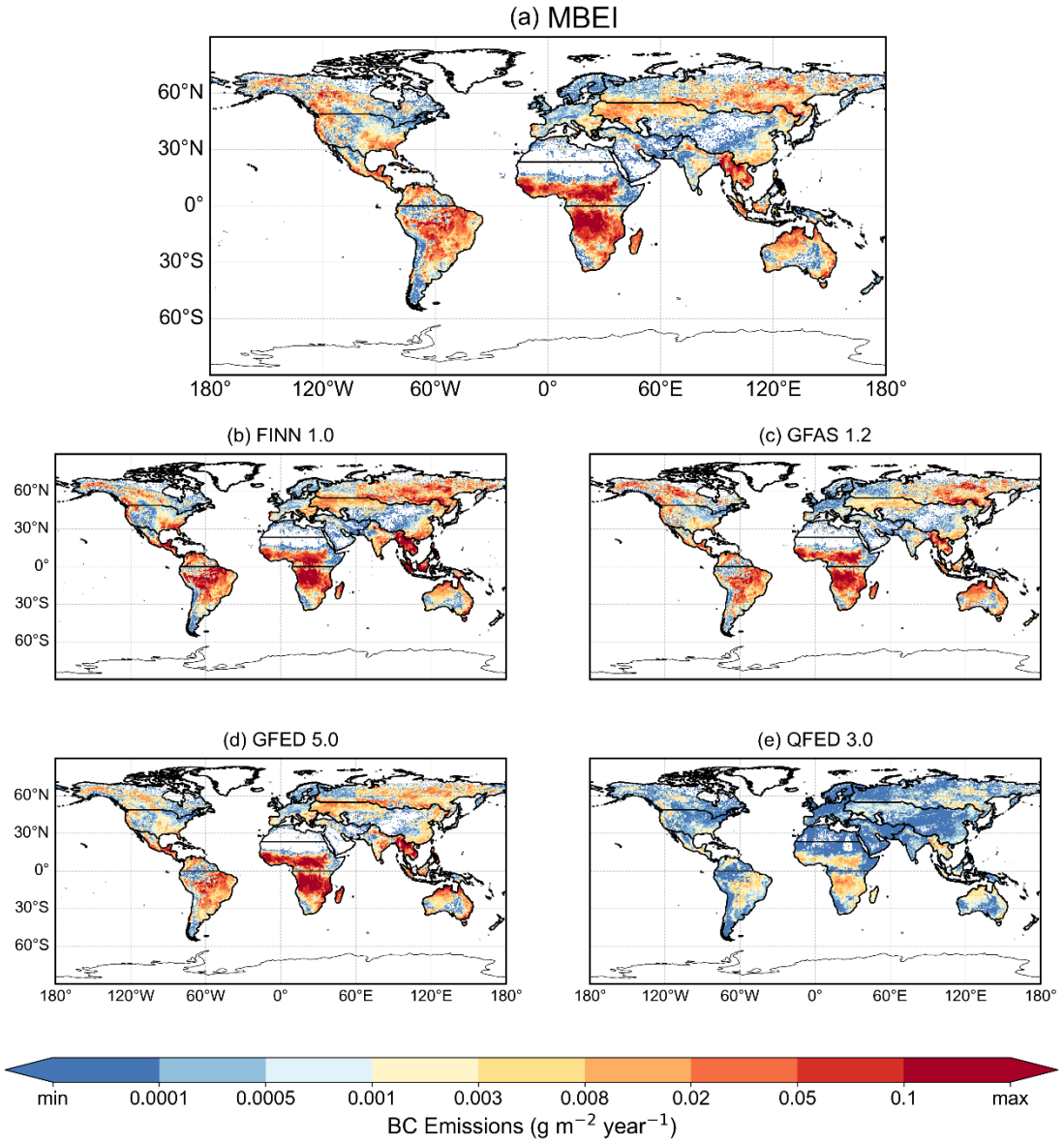

Figure S10. Comparison of multi-year mean spatial patterns of global BC emissions estimated by different biomass burning inventories.

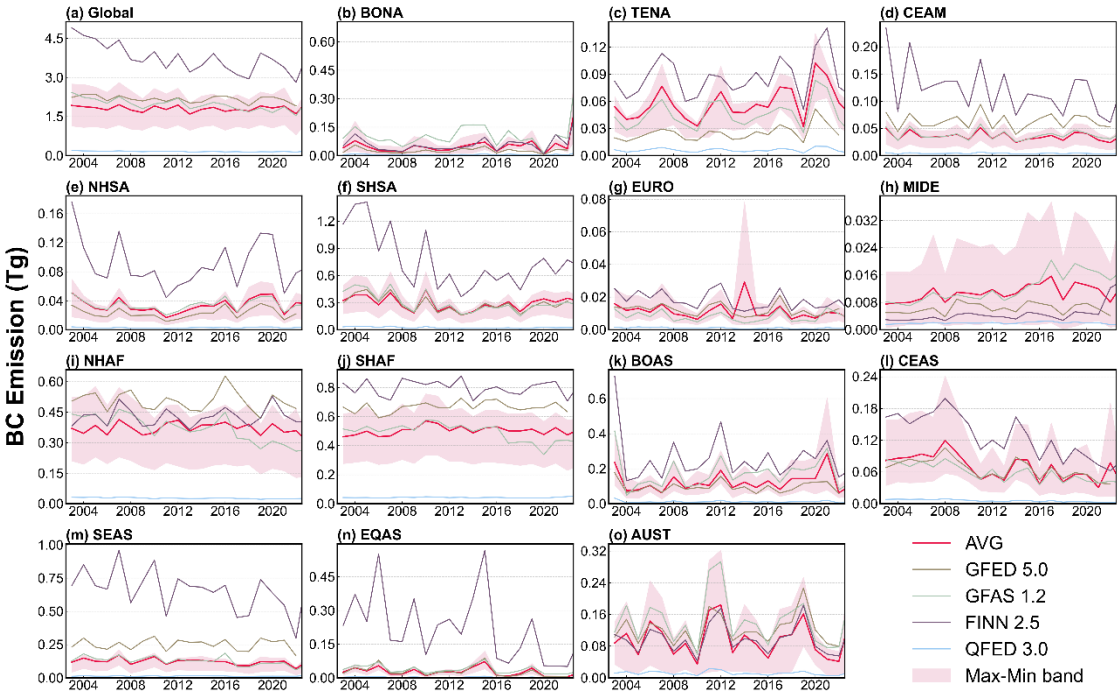

Figure S11. Time series of interannual variability in biomass burning BC emissions from different inventories at global and regional scales (2003–2022).

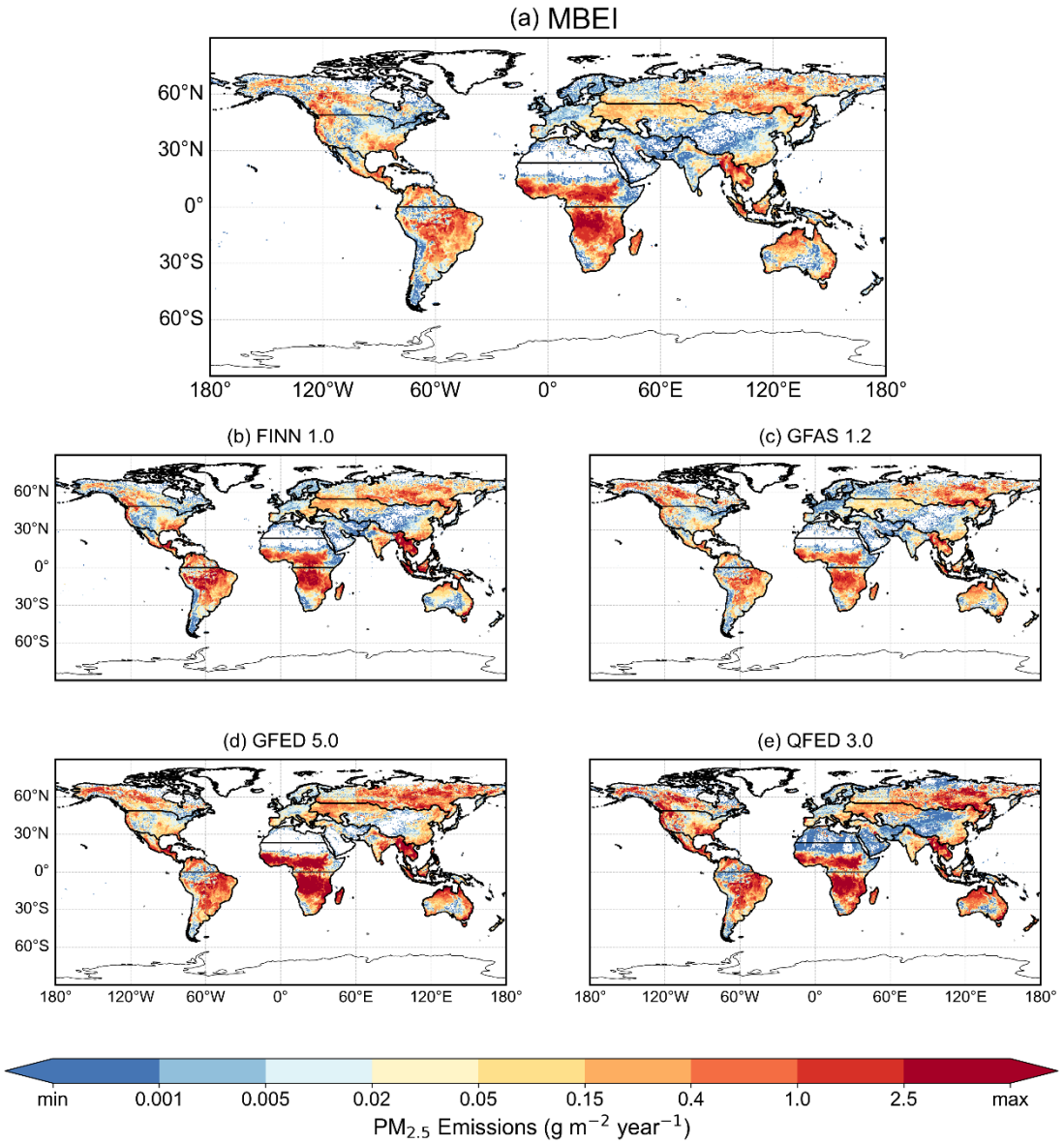

Figure S12. Comparison of multi-year mean spatial patterns of global $PM_{2.5}$ emissions estimated by different biomass burning inventories.

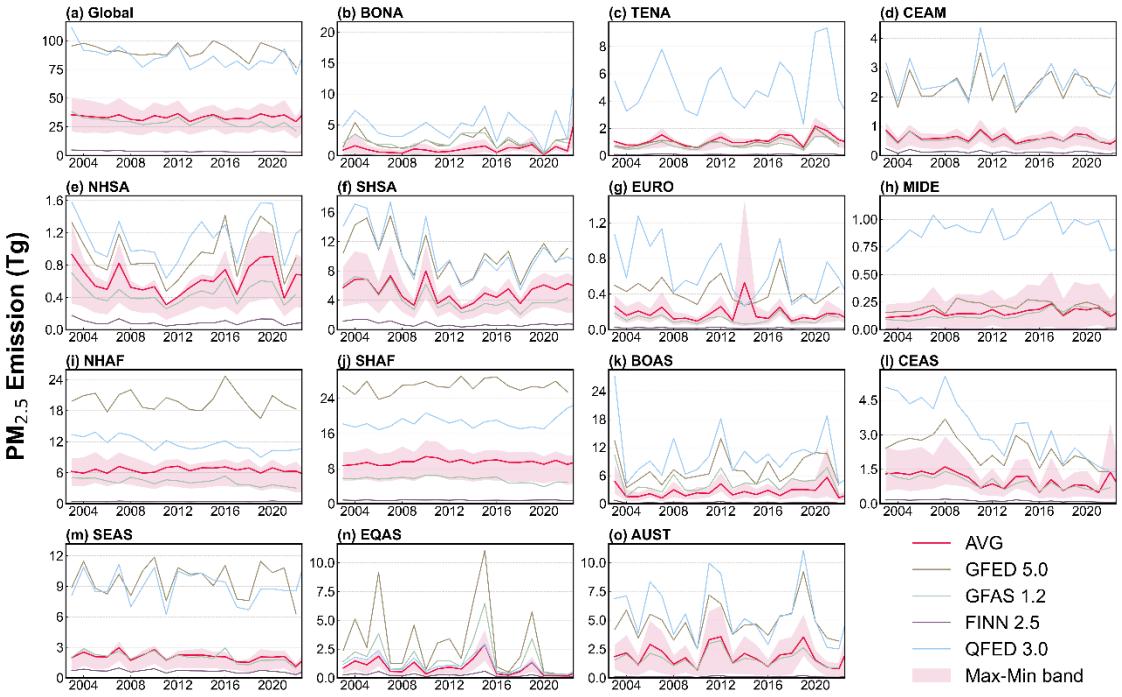

Figure S13. Time series of interannual variability in biomass burning $PM_{2.5}$ emissions from different inventories at global and regional scales (2003–2022).

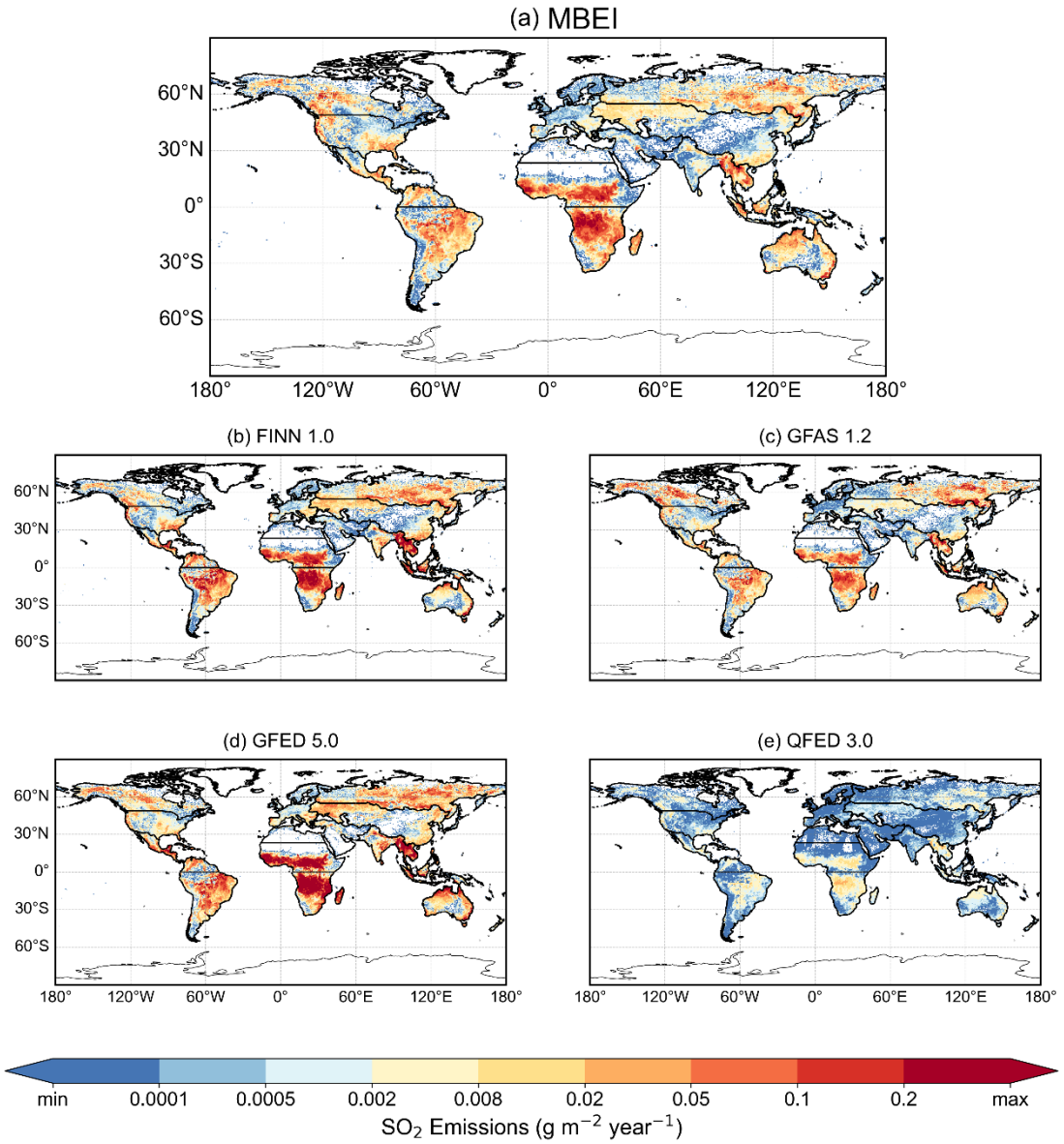

Figure S14. Comparison of multi-year mean spatial patterns of global SO_2 emissions estimated by different biomass burning inventories.

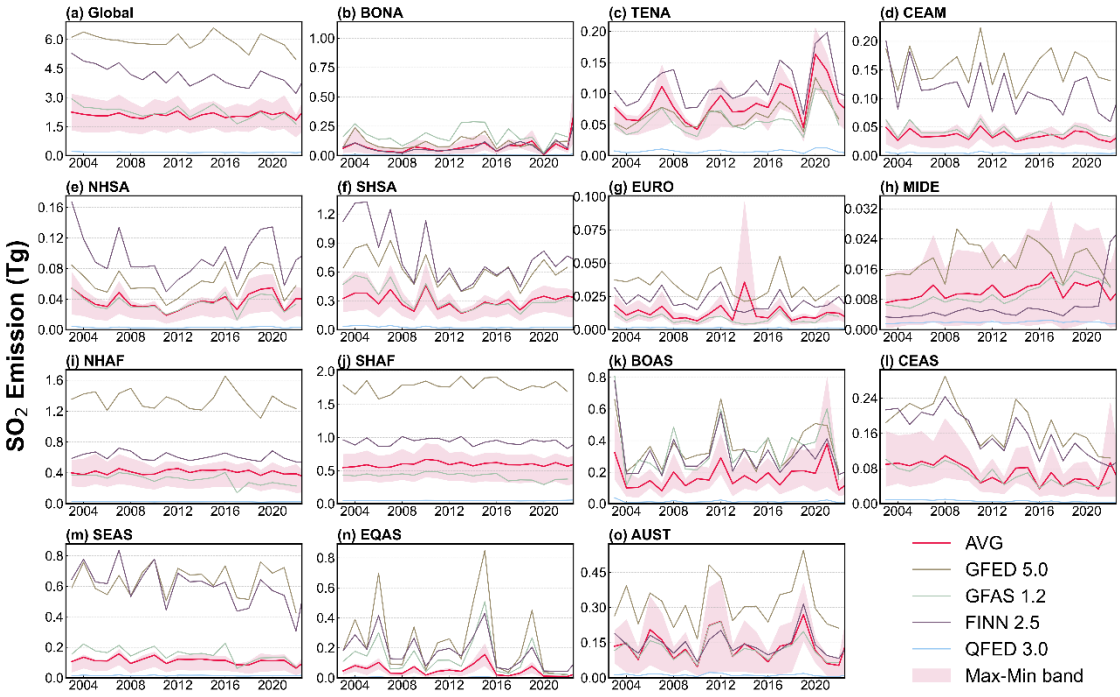

Figure S15. Time series of interannual variability in biomass burning SO_2 emissions from different inventories at global and regional scales (2003–2022).

Supplementary Table

2 Materials and Methods

2.1 Datasets

Table S1. 8-class conversion factor (unit: kg MJ^{-1}).

Biomass Burning Region Types	Land Use Types	Conversion Factor
Savanna	Tropical bare Boreal bare Temperate bare Tropical sparse Boreal sparse Temperate sparse Tropical grassland Boreal grassland Temperate grassland Low woodland savanna Boreal shrubland Temperate shrubland High woodland savanna	0.78
Agriculture	Tropical cropland Boreal cropland Temperate cropland	0.29
Extratropical forest	Boreal broadleaf evergreen Boreal broadleaf deciduous Boreal needleleaf evergreen Boreal needleleaf deciduous Temperate broadleaf evergreen Temperate broadleaf deciduous Temperate needleleaf evergreen Temperate needleleaf deciduous	0.49
Tropical forest	Tropical forest	0.96
Peat	Boreal peat Temperate peat Tropical peat	5.87
Savannah with organic soil	Savannah with organic soil	0.26
Agriculture with organic soil	Agriculture with organic soil	0.29
Extratropical forest with organic soil	Extratropical forest with organic soil	1.55

Table S2. 30-class conversion factor (unit: kg MJ^{-1}).

Biomass Burning Region Types	Conversion Factor
Boreal bare	1.8241
Boreal sparse	1.8241
Boreal cropland	1.8241
Boreal grassland	1.8241
Boreal shrubland	1.8241
Boreal broadleaf evergreen	2.7133
Boreal broadleaf deciduous	1.3665
Boreal needleleaf evergreen	0.99567
Boreal needleleaf deciduous	1.6849
Temperate bare	0.51885
Temperate sparse	0.51885
Temperate cropland	1.4186
Temperate grassland	0.76647
Temperate shrubland	0.85471
Temperate broadleaf evergreen	1.8319
Temperate broadleaf deciduous	0.93617
Temperate needleaf evergreen	0.58588
Temperate needleaf deciduous	0.79160
Tropical bare	0.51885
Tropical sparse	0.51885
Tropical cropland	2.0019
Tropical grassland	0.99165
Low woodland savanna	1.8138
High woodland savanna	1.6255
Tropical forest	2.4320
Boreal peat	1.5195
Temperate peat	1.5195
Tropical peat	3.1983

Table S3. Burning Efficiency.

Land Use Types	Burning Efficiency
Evergreen needleleaf forests	0.25
Evergreen broadleaf forests	0.25
Deciduous needleleaf forests	0.25
Deciduous broadleaf forests	0.25
Mixed forests	0.25
Closed shrublands	0.9
Open shrublands	0.9
Woody savannas	0.35
Savannas	0.35
Grasslands	0.75
Permanent wetlands	0.0
Croplands	0.8
Urban and built-up lands	0.0
Cropland/natural vegetation mosaics	0.8
Permanent snow and ice	0.0
Barren	0.0
Water bodies	0.0

Table S4. CO_2 emission factors based on MCD12Q1.

Region	Evergreen Needleleaf Forests	Evergreen Broadleaf Forests	Deciduous Needleleaf Forests	Deciduous Broadleaf Forests	Mixed Forests	Closed Shrublands	Open Shrublands	Woody Savannas	Savannas	Grasslands	Croplands	Cropland/ Natural Vegetation Mosaics
BONA	1489	1489	1489	1489	1489	1686	1686	1686	1686	1686	1585	1585
TENA	1647	1647	1647	1647	1647	1686	1686	1686	1686	1686	1585	1585
CEAM	1643	1643	1643	1643	1643	1686	1686	1686	1686	1686	1585	1585
NHSA	1643	1643	1643	1643	1643	1686	1686	1686	1686	1686	1585	1585
SHSA	1643	1643	1643	1643	1643	1686	1686	1686	1686	1686	1585	1585
EURO	1647	1647	1647	1647	1647	1686	1686	1686	1686	1686	1585	1585
MIDE	1643	1643	1643	1643	1643	1686	1686	1686	1686	1686	1585	1585
NHAF	1643	1643	1643	1643	1643	1686	1686	1686	1686	1686	1585	1585
SHAF	1643	1643	1643	1643	1643	1686	1686	1686	1686	1686	1585	1585
BOAS	1489	1489	1489	1489	1489	1686	1686	1686	1686	1686	1585	1585
CEAS	1647	1647	1647	1647	1647	1686	1686	1686	1686	1686	1585	1585
SEAS	1643	1643	1643	1643	1643	1686	1686	1686	1686	1686	1585	1585
EQAS	1643	1643	1643	1643	1643	1686	1686	1686	1686	1686	1585	1585
AUST	1647	1647	1647	1647	1647	1686	1686	1686	1686	1686	1585	1585

3 Result

3.1 Spatial patterns and uncertainty of global biomass burning emissions

Table S5. Annual total emissions of 10 species during 2003–2023 (average, maximum, and minimum values across eight biomass burning inventories; unit: Tg).

(Continued on the next page)

Year	BC			C			CH_4			CO		
	max	min	avg	max	min	avg	max	min	avg	max	min	avg
2003	2.74	1.14	1.92	3183.07	1314.96	2247.76	18.30	8.00	13.68	469.66	198.45	337.57
2004	2.73	1.08	1.87	3171.84	1253.71	2205.41	18.73	8.21	14.10	468.69	192.72	334.47
2005	2.63	1.11	1.84	3041.59	1275.32	2148.57	18.32	8.01	13.73	452.16	193.15	325.95
2006	2.42	1.04	1.75	2830.69	1222.29	2077.87	17.34	8.20	13.81	425.18	189.87	320.12
2007	2.80	1.18	1.95	3234.11	1359.73	2269.00	18.50	8.36	13.63	473.58	204.57	337.72
2008	2.49	1.02	1.75	2842.67	1179.96	2026.61	16.15	7.02	11.98	415.97	175.98	300.36
2009	2.18	0.98	1.65	2533.91	1151.89	1954.95	14.97	7.20	12.38	374.70	174.00	295.43
2010	2.58	1.16	1.90	2996.10	1386.43	2211.11	16.85	7.57	13.15	436.62	199.99	328.77
2011	2.37	1.03	1.77	2817.12	1206.02	2106.74	15.12	7.20	12.19	403.54	179.81	309.22
2012	2.59	1.18	1.94	3077.65	1383.48	2310.79	16.85	8.41	13.65	446.13	208.92	343.45
2013	2.01	0.97	1.59	2382.46	1195.21	1897.72	12.98	6.53	11.05	342.46	172.26	278.75
2014	2.28	1.11	1.77	2707.39	1315.70	2128.89	15.67	8.14	13.31	397.96	198.53	320.75
2015	2.37	1.16	1.85	2840.07	1480.52	2264.43	18.03	10.32	16.00	429.72	232.11	354.75
2016	2.12	0.98	1.70	2476.47	1184.72	1986.70	13.70	6.29	11.65	360.26	169.91	294.77
2017	2.34	1.12	1.77	2703.62	1298.87	2059.93	15.17	7.22	11.91	395.15	194.17	303.91
2018	2.15	1.04	1.71	2547.77	1218.91	2021.18	13.71	7.06	11.62	367.06	183.45	297.69
2019	2.44	1.19	1.91	2853.86	1459.14	2245.52	16.84	8.96	14.10	426.52	220.56	341.95
2020	2.34	1.06	1.83	2715.49	1276.26	2120.56	15.02	6.66	12.30	394.47	181.56	313.13
2021	2.60	1.19	1.90	3119.18	1395.36	2250.90	16.18	7.51	12.48	442.78	207.69	327.00
2022	1.80	0.80	1.61	2126.69	975.75	1883.60	11.89	4.96	10.80	307.06	137.22	276.18
2023	2.59	1.31	2.10	3080.98	1526.96	2492.24	17.28	9.44	14.72	459.16	233.03	375.93
avg	2.41	1.09	1.81	2822.99	1288.63	2138.59	16.08	7.68	12.96	413.75	192.76	319.90

Table S5. Annual total emissions of 10 species during 2003–2023 (average, maximum, and minimum values across eight biomass burning inventories; unit: Tg).

(Continued on the next page)

Year	N_2O			NH_3			NOx		
	max	min	avg	max	min	avg	max	min	avg
2003	1.28	0.54	0.91	5.22	2.21	3.69	23.28	9.29	16.13
2004	1.26	0.51	0.88	5.13	2.14	3.61	23.23	8.77	15.77
2005	1.20	0.51	0.86	4.98	2.15	3.55	22.21	9.00	15.35
2006	1.13	0.50	0.83	4.66	2.08	3.44	20.51	8.49	14.70
2007	1.28	0.55	0.90	5.20	2.26	3.67	23.77	9.61	16.35
2008	1.11	0.48	0.81	4.67	1.94	3.30	21.13	8.44	14.75
2009	1.00	0.46	0.78	4.11	1.88	3.15	18.70	8.19	14.07
2010	1.20	0.57	0.89	4.78	2.09	3.62	22.10	10.18	15.92
2011	1.13	0.49	0.85	4.26	1.96	3.26	21.11	8.63	15.41
2012	1.26	0.58	0.95	4.80	2.32	3.69	22.81	9.77	16.71
2013	0.95	0.49	0.76	3.60	1.69	2.91	17.78	8.62	13.83
2014	1.09	0.54	0.86	4.26	2.14	3.39	19.98	9.33	15.31
2015	1.14	0.61	0.91	4.56	2.32	3.68	20.56	10.24	15.89
2016	1.00	0.49	0.81	3.95	1.76	3.23	18.29	8.78	14.31
2017	1.08	0.53	0.83	4.39	2.04	3.32	19.92	9.19	14.91
2018	1.04	0.51	0.83	3.94	1.97	3.20	18.96	8.59	14.67
2019	1.16	0.60	0.92	4.69	2.30	3.71	20.53	10.01	15.80
2020	1.07	0.51	0.85	4.26	1.83	3.38	19.97	9.45	15.24
2021	1.27	0.57	0.92	4.61	2.10	3.47	23.39	9.88	16.45
2022	0.85	0.40	0.76	3.27	1.38	2.98	15.91	7.34	13.68
2023	1.33	0.65	1.07	5.25	2.65	4.25	22.20	10.63	17.68
avg	1.13	0.53	0.87	4.51	2.06	3.45	20.78	9.16	15.38

Table S5. Annual total emissions of 10 species during 2003–2023 (average, maximum, and minimum values across eight biomass burning inventories; unit: Tg).

(Continued on the next page)

Year	OC			$PM_{2.5}$			SO_2		
	max	min	avg	max	min	avg	max	min	avg
2003	20.34	9.16	13.26	49.61	21.20	31.76	3.17	1.32	2.02
2004	19.71	8.61	12.74	48.73	20.02	30.85	3.05	1.21	1.92
2005	18.88	8.64	12.42	46.66	20.28	30.09	2.91	1.22	1.86
2006	18.25	8.61	12.31	44.08	19.71	29.16	2.81	1.22	1.84
2007	20.14	9.28	13.29	49.73	21.69	32.13	3.13	1.32	2.01
2008	17.07	7.96	11.31	43.11	18.75	27.88	2.76	1.17	1.77
2009	15.47	7.78	10.90	38.60	18.27	26.51	2.47	1.13	1.68
2010	18.56	8.75	12.97	46.12	21.55	31.40	2.90	1.37	1.95
2011	17.02	8.07	11.80	42.99	19.16	29.14	2.77	1.18	1.85
2012	19.25	9.64	13.58	47.73	22.42	32.86	3.08	1.39	2.10
2013	14.49	7.40	10.60	36.37	18.50	26.02	2.33	1.17	1.65
2014	16.81	9.01	12.35	41.65	21.05	29.80	2.68	1.31	1.89
2015	18.11	10.06	13.53	44.00	23.73	31.94	2.79	1.46	1.99
2016	15.51	7.57	11.62	38.36	18.53	28.04	2.45	1.20	1.77
2017	16.92	8.67	12.05	41.80	20.97	29.13	2.66	1.29	1.84
2018	15.80	8.59	11.76	39.36	19.86	28.54	2.54	1.24	1.82
2019	19.34	10.07	14.26	45.48	23.52	32.83	2.94	1.52	2.10
2020	17.39	8.30	12.81	42.17	19.97	30.28	2.71	1.30	1.92
2021	19.14	9.37	13.09	47.98	22.60	31.91	3.10	1.40	2.03
2022	13.64	5.97	10.54	33.00	14.99	25.78	2.08	0.96	1.61
2023	21.24	11.00	15.67	50.26	25.16	36.63	3.28	1.55	2.36
average	17.77	8.69	12.52	43.71	20.57	30.13	2.79	1.28	1.90