Assessing the Impacts of Emission Uncertainty on Aerosol Optical Properties and Radiative Forcing from Biomass Burning in Peninsular Southeast Asia

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Figure

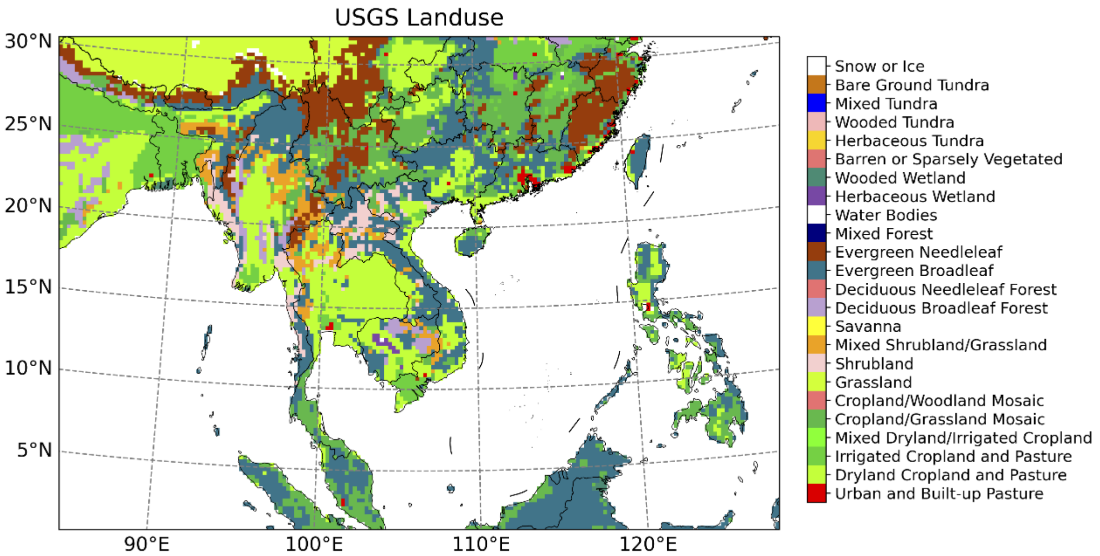

Figure S1. WRF-Chem uses land use classification data from 24 USGS classifications.

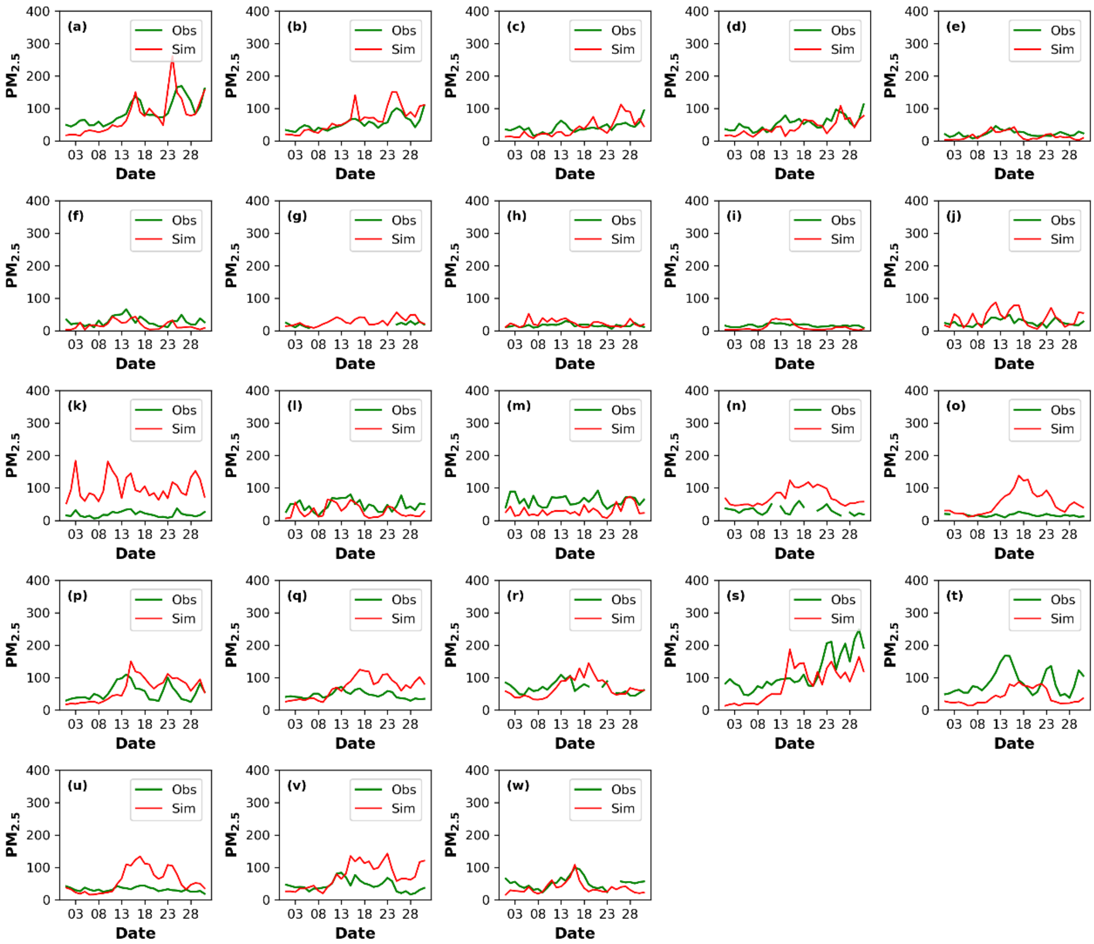

Figure S2. Time series of the observed (green lines) and simulated (red lines) daily average of $PM_{2.5}$ concentrations from WRF-Chem with FINN 1.5 in the 23 cities in Table S6 during March 2019.

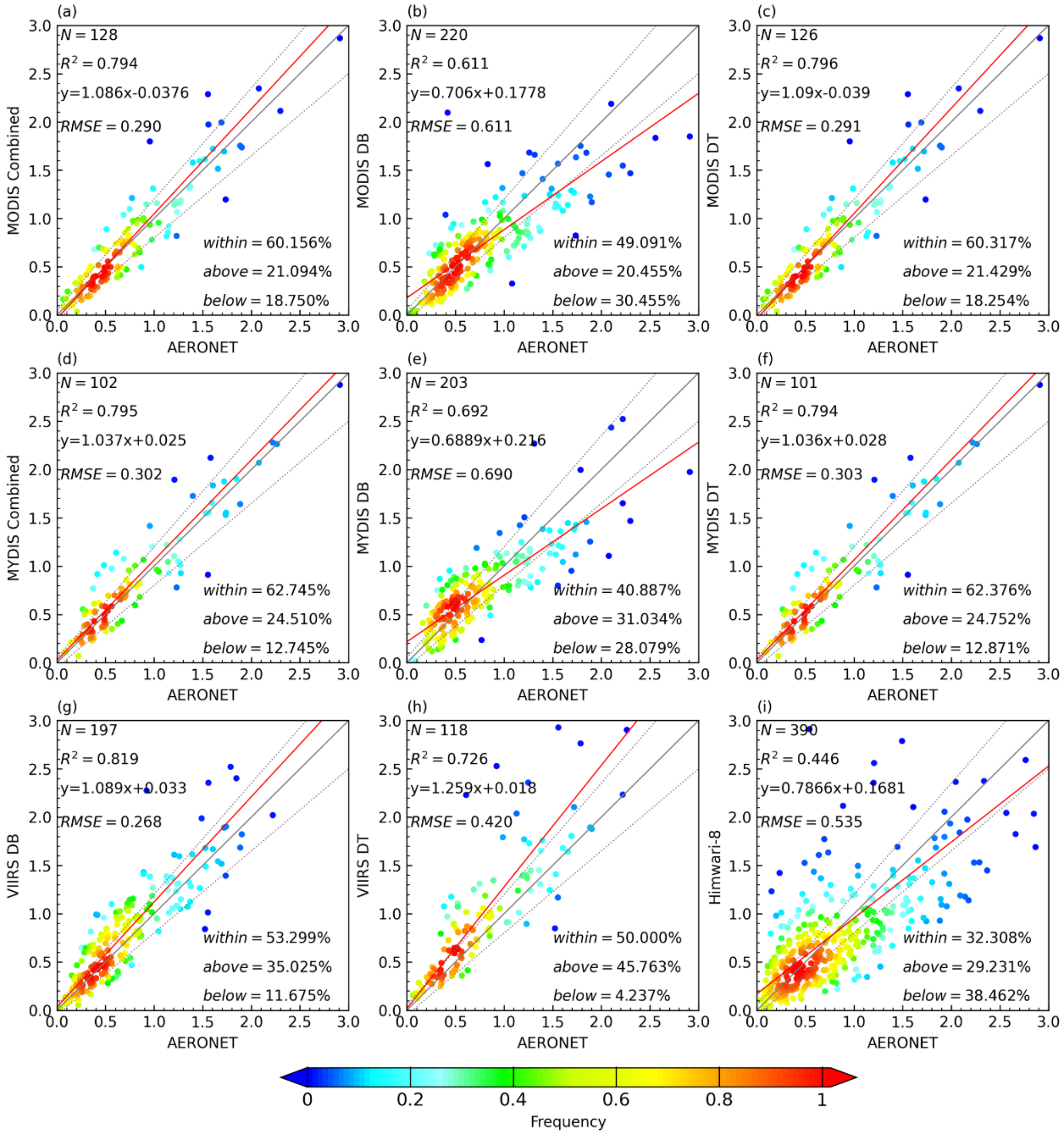

Figure S3. Satellite-AERONET linear regression, where (a)-(h) denote MODIS combined, MODIS DB, MODIS DT, MYDIS combined, MYDIS DB, MYDIS DT, VIIRS DB, VIIRS DT different satellite inversion AOD (550 nm) products compared with AERONET, (i) is Himawari-8 AOD (500 nm) vs. AERONET. The number of samples (N), R^2 correlation coefficient squared, and linear regression function and RMSE are also labeled in the upper left corner of each figure, and the lower right corner characterizes the expected values.

Tables

Table S1. Emission factors (g kg^{-1}) for species emitted from different types of biomass burning in GFED.

Species	Sava	Borf	Temf	Defo	Peat	Agri
CO	63	127	88	93	210	102
NO_X	3.9	0.9	1.92	2.55	1	3.11
SO2	0.48	1.1	1.1	0.4	0.4	0.4
BIGALK	0.055	0.349	0.225	0.072	0.072	0.34
BIGENE	0.133	0.385	0.369	0.267	0.267	0.333
C2H4	0.82	1.42	1.17	1.06	2.57	1.46
C2H5OH	0.024	0.055	0.1	0.037	0.037	0.035
C2H6	0.66	1.79	0.63	0.71	0.71	0.91
C3H8	0.1	0.44	0.22	0.126	0.126	0.28
C3H6	0.79	1.13	0.61	0.64	3.05	0.68
CH2O	0.73	1.86	2.09	1.73	1.4	2.08
CH3CHO	0.84	0.81	1.21	2.26	1.16	1.8
CH3COCH3(C3H6O)	0.47	1.59	0.76	0.63	0.91	0.71
CH3OH	1.18	2.82	1.74	2.43	8.46	3.29
MEK	0.181	0.22	0.13	0.5	0.5	0.9
TOLUENE	0.27	1.626	0.54	0.697	4.36	0.451
NH3	0.52	2.72	0.84	1.33	1.33	2.17
NO2	2.92	0.67	1.44	1.91	0.75	2.33
Open/BIGALD(C5H6O2)	0.02	0.01	0.01	0.01	0	0.01
C10H16	0.081	2.003	2.003	0.15	0.15	0.005
CH3COOH	3.55	4.41	2.13	3.05	8.97	5.59
CRESOL	0.44	0.85	0.07	0.17	0	0.6
GLYALD(HOCH2CHO)	0.25	0.86	0.86	0.74	0.74	0.71
Mgly/CH3COCHO	0.73	0.73	0.73	0.73	0.73	0.73
Gly/CH3COCHO	0.33	0.59	0.54	0.5	1.3	0.24
ACETOL/HYAC	1.01	0.77	8.03	0.55	0.64	0
ISOP(C5H8)	0.039	0.15	0.099	0.13	1.38	0.38
MACR	0	0	0	0.08	0	0
MVK	0	0	0	0.2	0	0
OC	2.62	9.6	9.6	4.71	6.02	2.3
BC	0.37	0.5	0.5	0.52	0.04	0.75
PM_{10}	7.2	18.4	16.97	18.5	0	7.02
$PM_{2.5}$	7.17	15.3	12.9	9.1	9.1	6.26

Note: Sava: Savanna, grassland, and shrubland fires; Borf: Boreal forest fires; Temf: Temperate forest fires; Defo: Tropical deforestation & degradation; Peat: Peat fires; Agri: Agricultural waste burning. Compared to the FINNs scheme, the missing compounds and aerosols (marked in red) were added based on the methodology of Akagi et al. (2011) and Heil A. (2020)..

Table S2. Emission factors (g kg^{-1}) for species emitted from different types of biomass burning in FINN1.5.

Species	Savanna	Tropical	Temperate	Agriculture	Boreal	Shrublands
CO	59	92	102	111	118	68
NO	0.38	0.74	0.26	0.09	0.70	0.74
SO2	0.48	0.45	1	0.4	1	0.68
BIGALK	0.02	0.13	0.11	0.09	0.16	0.42
BIGENE	0.45	0.52	0.22	0.37	0.35	0.63
C2H4	2.27	1.38	1.11	1.08	1.62	2.30
C2H5OH	0.02	0.01	0.01	0.01	0.01	0.02
C2H6	0.82	0.82	0.29	0.43	1.63	1.01
C3H8	0.18	0.10	0.10	0.08	0.13	0.37
C3H6	0.43	0.56	0.26	0.38	0.76	0.77
CH2O	2.12	2.08	1.33	1.84	1.46	2.23
CH3CHO	1.03	1.27	0.38	3.05	0.67	0.96
CH3COCH3	0.22	0.39	0.20	0.83	0.20	0.71
CH3OH	1.92	2.60	1.51	2.11	2.50	2.49
MEK	1.31	0.85	0.41	0.79	1.64	1.16
TOLUENE	1.16	2.06	0.61	1.07	1.30	1.30
NH3	0.49	0.76	1.5	2.3	3.5	1.2
NO2	3.2	3.6	2.7	3.9	3	1.4
Open/BIGALD	0.02	0.01	0.01	0.01	0.01	0.02
C10H16	0.01	0.04	0.03	0.00	0.04	0.01
CH3COOH	2.08	1.87	0.53	2.19	1.80	1.24
CRESOL	0.44	0.17	0.07	0.60	0.85	0.00
GLYALD	0.5	0.79	0.28	1.68	0.25	1.39
Mgly/CH3COCHO	0.81	0.37	0.17	0.19	0.28	0.86
Gly/CH3COCHO	0.81	0.37	0.17	0.19	0.28	0.86
ACETOL/HYAC	1.01	0.55	8.03	0.00	0.77	0.00
ISOP	0.05	0.07	0.03	0.60	0.14	0.03
MACR	0.0	0.08	0.0	0.0	0.0	0.0
MVK	0.0	0.20	0.0	0.0	0.0	0.0
OC	2.6	4.7	9.2	3.3	7.8	6.6
BC	0.37	0.52	0.56	0.69	0.2	0.5
$PM_{2.5}$	5.4	9.7	13	5.8	13	9.3

Table S3. Emission factors (g kg^{-1}) for species emitted from different types of biomass burning in FINN2.5.

Species		Savanna	Tropical	Temperate	Agriculture	Boreal	Shrublands
CO		63	93	122	91	111	67
NO		2.16	0.9	0.95	1.18	0.83	0.77
SO2		0.9	0.4	1.1	0.4	1	0.68
BIGALK		0.156	0.219	0.415	0.246	1.821	0.644
BIGENE		1.467	0.662	1.393	0.674	0.627	1.274
C2H4		1.218	1.505	1.930	1.412	1.407	2.886
C2H5OH		0.00	0.00	0.066	0.0	0.023	0.055
C2H6		0.859	0.939	0.611	0.673	1.168	0.641
C3H8		0.09	0.114	0.149	0.142	0.194	0.561
C3H6		0.647	0.603	0.487	0.457	0.499	0.557
CH2O		1.532	2.299	2.181	1.716	1.361	2.285
CH3CHO		1.037	1.404	0.758	0.929	0.416	0.792
CH3COCH3		0.201	0.433	0.297	0.162	0.242	0.242
CH3OH		1.451	3.031	1.744	2.328	1.608	1.650
MEK		0.37	0.666	0.274	0.387	0.104	0.286
TOLUENE		0.457	0.769	0.605	0.375	1.327	0.531
NH3		0.56	1.3	2.47	2.12	1.8	1.2
NO2		3.22	3.6	2.34	2.99	0.63	2.58
Open/BAZLD		0.791	0.12	0.298	0.325	0.166	0.272
C10H16	APIN	0.009	0.0	0.261	0.01	0.259	0.053
	BPIN	0.0	0.0	0.008	0.0	0.209	0.004
CH3COOH		2.371	2.029	1.292	2.349	1.36	1.353
CRESOL		0.059	0.0	0.059	0.074	0.04	0.058
GLYALD		0.390	1.886	0.210	0.800	0.233	0.128
MGLY(CH3COCHO)		0.347	0.0	0.135	0.171	0.09	0.094
GLY(CH3COCHO)		0.347	0.0	0.135	0.171	0.09	0.094
ACETOL/ HYAC		0.309	0.609	0.223	1.548	0.149	0.118
ISOP		0.069	0.029	0.129	0.062	0.085	0.138
MACR		0.0	0.222	0.113	0.0	0.024	0.147
MVK		0.317	0.222	0.247	0.193	0.087	0.301
OC		2.6	4.7	7.6	2.66	7.8	3.7
BC		0.37	0.52	0.56	0.51	0.2	1.31
PM_{10}		7.2	18.5	16.97	7.02	18.4	11.4
$PM_{2.5}$		7.17	9.9	15	6.43	18.4	7.1

Table S4. Emission factors (g kg^{-1}) for species emitted from different types of biomass burning in GFAS.

Species	Savanna	Tropical	Temperate	Agriculture
CO	61	101	106	92
NO_X	2.1	2.3	3.4	2.3
SO_2	0.37	0.71	1.0	0.37
BIGALK	0.13	0.17	0.29	0.41
BIGENE	0.32	0.51	0.47	0.28
C2H4	0.84	1.5	1.2	1.3
C2H5OH	0.018	0.018	0.018	0.018
C2H6	0.32	1.1	0.72	1.2
C3H8	0.087	0.54	0.27	0.16
C3H6	0.34	0.76	0.57	0.57
CH2O	1.06	2.2	2.2	2.1
CH3CHO(C2H4O)	0.5	2.3	0.98	2.8
CH3COCH3(C3H6O)	0.48	0.63	0.67	1.1
CH3OH	1.5	3.0	1.9	3.7
MEK	0.37	0.666	0.274	0.387
TOLUENE(C7H8)	0.18	0.24	0.40	0.18
NH_3	0.90	0.93	1.6	1.6
NO_2	1.575	1.725	2.55	1.725
Open/BAZLD	0.791	0.12	0.298	0.325
C10H16	0.009	0.0	0.269	0.01
CH3COOH	2.371	2.029	1.292	2.349
CRESOL	0.059	0.0	0.059	0.074
GLYALD	0.390	1.886	0.210	0.800
MGLY(CH3COCHO)	0.347	0.0	0.135	0.171
GLY(CH3COCHO)	0.347	0.0	0.135	0.171
ACETOL/ HYAC	0.309	0.609	0.223	1.548
ISOP(C5H8)	0.026	0.22	0.11	0.40
MACR	0.0	0.222	0.113	0.0
MVK	0.317	0.222	0.247	0.193
OC	3.2	4.3	9.1	4.2
BC	0.46	0.57	0.56	0.42
PM_{10}	7.2	18.5	16.97	7.02
$PM_{2.5}$	4.9	9.1	13.8	8.3

Note: Compared to the FINNs scheme, the missing compounds and aerosols (marked in red) were added based on the methodology of Andreae and Merlet (2001;2019).

Table S5. Missing data supplementation of FEER, QFED and IS4FIRES emission inventories based on the proportionality approach when WRF-Chem uses the MOZART-MOSAIC chemical mechanism.

Species	FEER	QFED	IS4FIRES
CO	NM	NM	9.18
NO_X	NM	NM	0.29
SO_2	NM	NM	0.05
BIGALK	0.001	0.001	0.001
BIGENE	0.0041	0.0041	0.0041
C2H4	0.0109	0.0109	0.093
C2H5OH	0.0001	0.0001	0.0001
C2H6	NM	NM	0.2520
C3H8	NM	NM	0.0270
C3H6	NM	NM	0.059
CH2O	NM	NM	0.18
CH3CHO	0.01	NM	0.14
CH3COCH3	NM	NM	0.07
CH3OH	NM	0.0206	0.27
MEK	NM	NM	0.0067
TOLUENE	0.0163	0.0163	0.0163
NH_3	NM	NM	0.1
NO_2	0.75*NO_X	NM	0.08
Open	0.0001	0.0001	0.0001
C10H16	0.0003	0.0003	0.0003
CH3COOH	0.0148	0.0148	0.0148
CRESOL	0.0013	0.0013	0.0013
GLYALD	0.0062	0.0062	0.0062
MGLY	0.0029	0.0029	0.0029
GLY	0.0029	0.0029	0.0029
ACETOL	0.0044	0.0044	0.0044
ISOP	0.0006	0.0006	0.03
MACR	0.0006	0.0006	0.0006
MVK	0.0016	0.0016	0.0016
OC	NM	NM	0.373
BC	NM	NM	0.054
PM_{10}	0.3*$PM_{2.5}$	NM	0.3
$PM_{2.5}$	NM	NM	NM

Notes: FEER,QFED emission inventories compared to the MOZART-MOSAIC mechanism missing data were supplemented through a combination of methodology of Jose et al. (2017), Andreae and Merlet (2001;2019) and the actual FINN data (March 2019 over PESA), where CO was used as as a scaling factor. The IS4FIRES was supplemented with other substances through a combination of methodology of Jose et al. (2017), Andreae and Merlet (2001;2019), Baró et al. (2021), and Wiedinmyer et al. (2011) using $PM_{2.5}$ and CO as scaling factors. NO_2 using 0.75*NO_X. PM_{10} using 0.3*$PM_{2.5}$. NM: No missing data.

Table S6. Comparison statistics of meteorological variables simulated by WRF-Chem with FINN1.5 scheme and observation stations

Stations	variables	MB	RMSE	IOA	R
	T(°C)	-0.85	2.56	0.91	0.91
56964	RH (%)	5.17	17.67	0.83	0.7
	WS(m/s)	1.76	2.35	0.64	0.51
	T(°C)	-0.95	2.33	0.91	0.95
56969	RH (%)	-13.58	20.69	0.82	0.82
	WS(m/s)	2.69	3.08	0.61	0.52
	T(°C)	0.97	3.71	0.79	0.65
59431	RH (%)	0.78	9.51	0.8	0.62
	WS(m/s)	1.85	2.71	0.66	0.31
	T(°C)	1.29	3.87	0.71	0.54
59644	RH (%)	7.62	11.2	0.72	0.4
	WS(m/s)	2.91	3.78	0.6	0.30
	T(°C)	-2.47	3.55	0.72	0.65
59758	RH (%)	11.33	15.09	0.74	0.66
	WS(m/s)	1.72	2.59	0.65	0.33
	T(°C)	1.0	2.75	0.83	0.79
59287	RH (%)	-8.01	15.03	0.77	0.65
	WS(m/s)	0.74	1.69	0.69	0.32
	T(°C)	-0.43	2.33	0.82	0.73
59663	RH (%)	-0.18	8.16	0.81	0.65
	WS(m/s)	0.55	1.82	0.71	0.33
	T(°C)	0.35	2.13	0.78	0.65
45011	RH (%)	0.82	7.64	0.79	0.65
	WS(m/s)	1.36	2.27	0.67	0.31
	T(°C)	-1.37	2.63	0.78	0.68
45007	RH (%)	7.66	12.62	0.74	0.66
	WS(m/s)	-2.09	3.16	0.71	0.40
	T(°C)	-2.76	3.35	0.72	0.83
48855	RH (%)	2.4	9.67	0.81	0.74
	WS(m/s)	1.62	2.12	0.66	0.62
	T(°C)	-3.42	4.61	0.82	0.85
48930	RH (%)	-7.51	18.09	0.82	0.72
	WS(m/s)	2.43	3.01	0.60	0.30
	T(°C)	-3.45	4.29	0.83	0.91
48327	RH (%)	-2.45	13.63	0.82	0.74
	WS(m/s)	1.86	2.54	0.6	0.30
	T(°C)	-1.71	2.56	0.82	0.85
58968	RH (%)	8.06	13.95	0.76	0.61
	WS(m/s)	1.61	2.48	0.71	0.45

Table S7. Comparison statistics of $PM_{2.5}$ simulated by WRF-Chem with FINN1.5 and air quality stations

Cites	latitude	longitude	MB	RMSE	IOA	R
Jing Hong	22	100.79	-11.2	38.44	0.82	0.75
Pu ER	22.76	100.98	11.92	26.32	0.8	0.84
Wen Shan	23.35	104.25	-2.77	24.97	0.7	0.41
Hong He Zhou	23.36	103.37	-13.24	23.04	0.77	0.62
Mao Ming	21.46	111.02	-6.69	12.35	0.72	0.51
Yang Jiang	21.85	111.95	-12.09	18.47	0.71	0.40
Guang Zhou	23.55	113.58	9.65	16.06	0.67	0.50
Hai Kou	20.05	110.32	6.53	11.34	0.66	0.45
San Ya	18.24	109.5	-5.55	10.62	0.67	0.69
Zhu Hai	22.42	113.62	13.6	24.72	0.69	0.51
Hongkong	22.32	114.25	82.21	88.43	0.54	0.43
Macao	22.15	113.56	-17.77	25.36	0.7	0.48
TW	25.013	121.511	-30.37	35.23	0.66	0.38
Saraburi	14.68	100.87	38.57	44.28	0.6	0.44
Ratchaburi	13.52	99.81	40.18	52.03	0.54	0.57
Chiang Mai	18.79	98.99	9.54	34.37	0.71	0.45
Lampang	18.25	99.76	24.0	37.95	0.63	0.35
Nakhon Sawan	15.68	100.11	-2.5	26.31	0.73	0.45
Chiang Rai Mueang	19.9	99.82	-33.81	56.82	0.74	0.64
Sa Kaeo	13.69	102.51	-43.66	56.3	0.68	0.36
Kanchanaburi	14.02	99.53	26.98	43.48	0.58	0.47
Nan	18.78	100.77	30.32	46.74	0.64	0.36
Hochi	10.78	106.7	-15.6	21.47	0.75	0.68

Table S8. Statistical metrics for observation-model comparisons

Mathematical formulas	Number
$MB = \frac{1}{N}\sum_{i=1}^{N}(P_i - O_i)$	（1）
$RMSE = [\frac{1}{N}\sum_{i=1}^{N}(P_i - O_i)^2]^{\frac{1}{2}}$	（2）
$IOA = 1 - \frac{\sum_{i=1}^{N}(P_i - O_i)^2}{\sum_{i=1}^{N}(\mid P_i - \bar{O} \mid + \mid O_i - \bar{O} \mid)^2}$	（3）

Note: Where P_i and O_i are the predicted and observed T_2, RH_2, WS_{10}, and $PM_{2.5}$, respectively. N is the total number of the predictions used for comparisons, and $\bar{P}$ and $\bar{O}$ represents the average of the prediction and observation, respectively.

Table S9. WRF-Chem AAOD at 500 nm vs. AERONET in HAAOD (97-110°E, 15-22.5°N) during the wildfire period, where HAAOD includes Laos, Doi Ang Khang, Fang, Nong Khai (all statistical days in 4 stations are greater than 10 days).

Stations	Variables	BB emission inventories							
		GFED	FINN1.5	FINN2.5MOS	FINN2.5 MOSVIS	GFAS	FEER	QFED	IS4FIRES
Laos	R	0.77	0.64	0.59	0.65	0.58	0.69	0.65	0.71
	IOA	0.63	0.67	0.71	0.71	0.63	0.65	0.63	0.64
Doi Ang Khang	R	0.07	0.37	0.31	0.64	NA	0.24	NA	0.14
	IOA	0.64	0.7	0.69	0.75	0.64	0.65	0.64	0.63
Fang	R	0.59	0.77	0.77	0.79	0.55	0.7	0.64	0.67
	IOA	0.66	0.7	0.76	0.74	0.65	0.66	0.66	0.67
Nong Khai	R	0.35	0.37	0.52	0.74	0.31	0.35	0.34	0.43
	IOA	0.7	0.72	0.76	0.78	0.68	0.73	0.7	0.73

Notes: The blank data in the table are not counted because the statistical correlation coefficient is negative and the value is particularly small, which we consider an error.
NA: Not available.

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