Supplement of

Global budgets of atmospheric primary and secondary organic aerosols constrained by full-volatility-range organic emissions

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Table S1. The OA species of the default complex OA scheme and the full-volatility-range OA scheme. S/LVOC-SOA, IVOC-SOA, AVOC-SOA, and BVOC-SOA are SOA formed from semivolatile and low-volatility organic compounds (S/LVOCs), intermediate-volatility organic compounds (IVOCs), aromatic volatile organic compounds (AVOCs), and biogenic volatile organic compounds (BVOCs), respectively. Aqueous SOA is SOA formed from heterogeneous uptake of isoprene epoxydiols, glyoxal, and methylglyoxal.

Category	Default complex OA scheme	Full-volatility-range OA scheme
POA	POA1, POA2	POA1, POA2, POA3, POA4, POA5
S/LVOC-SOA	OPOA1, OPOA2	OPOA1, OPOA2, OPOA3
IVOC-SOA	ASOA1, ASOA2, ASOA3, ASOAN	ASOA1, ASOA2, ASOA3, ASOA0
AVOC-SOA		IVSOA1, IVSOA2, IVSOA3, IVSOA0, IVSOAN
BVOC-SOA	TSOA1, TSOA2, TSOA3, TSOA0	TSOA1, TSOA2, TSOA3, TSOA0 ISOA1, ISOA2, ISOA3, ISOA0
Aqueous SOA	SOAGX, SOAIE, LVOCOA, IONITA, INDIOL, MONITA	SOAGX, SOAIE, LVOCOA, IONITA

Table S2. Updated SOA yield parameterizations for IVOCs at 298 K under high NO_x conditions. The saturation concentration (C^*) is in unit of μg m^{-3}. The correction factor to account for the vapor wall losses is 1.2 for all precursors (Zhang et al., 2014). We apply the same SOA yields for the IVOC species with C^* of 10^3 and 10^4 μg m^{-3} due to the lack of experiments for IVOC species with carbon numbers over 17 in their formulae.

Lumped precursors	C^*	Oxidant	Mass-based stoichiometric coefficients *(α)* for C^*				SOA yield at 10 μg m^{-3}	Reference
			0.1	1	10	100		
IVOC6	10^6	OH	0.011	0.052	0.201	0.296	0.19	Presto et al. (2010)
IVOC5	10^5		0.049	0.078	0.439	0.271	0.36	
IVOC4	10^4		0.063	0.089	0.550	0.200	0.44	Zhao et al. (2014)
IVOC3	10^3							

Table S3. Empirical scalars used to estimate the emissions of IVOCs and S/LVOCs from waste treatment and open biomass burning by scaling from corresponding NMVOC and OC emissions, respectively. The scalars for waste treatment refer to the experiments from Stewart et al. (2021) for municipal solid waste. The scalars for open biomass burning base on the experiments from Koss et al. (2018), Hatch et al. (2017), and May et al. (2013).

Category	C^* (μg m^{-3})	Waste treatment	Open biomass burning
IVOCs	10^6	0.155	0.088
	10^5	0.046	0.040
	10^4	0.036	0.004
	10^3	0.018	0.004
SVOCs	10^2	0.165	0.466
	10^1	0.686	0.234
	10^0	0.329	0.234
LVOCs	10^{-1}	0.055	0.000
	10^{-2}	0.165	0.466

Table S4. Descriptions of the simulation runs. "None" means excluding corresponding emissions from simulations.

Simulation runs	OA scheme	Wet deposition	Emissions of Organic Precursors		
			Anthropogenic emissions	Open biomass burning	Biogenic emissions
Default	Default complex OA scheme	Default wet deposition	CEDS w/ scalar suggested by Pye and Seinfeld (2010)	FINNv2.5 w/ scalar suggested by Pye and Seinfeld (2010)	MEGANv2.1
Default_emis			Amount: MEIC-global-FVOC + waste emissions from CEDS w/ scalar suggested by Chen et al. (2024) Volatility distribution: according to Pye and Seinfeld (2010)	Amount: FINNv2.5 w/ scalar suggested by Chen et al. (2024) Volatility distribution: according to Pye and Seinfeld (2010)	Same as Default
Base	Full-volatility-range OA scheme	Default wet deposition	MEIC-global-FVOC + waste emissions from CEDS w/ scalar suggested by Chen et al. (2024)	FINNv2.5 w/ scalar suggested by Chen et al. (2024)	MEGANv2.1
Zero_Biof			Same as Base but excluding residential biofuel emissions	---	Same as Base
Zero_Anthro			---	Same as Base	Same as Base
Zero_BioBurn			Same as Base	---	Same as Base
Zero_Biog			Same as Base	Same as Base	---
WDLuo		Luo et al. (2020)	Same as Base	Same as Base	Same as Base

Table S5. List of the year-long observed campaign-mean mass concentrations of OC in Asia, Africa, and Latin America adopted from literatures. “CN”, “KR”, “IN”, “VN”, “TH”, “MY”, “CI”, “BJ”, “ET”, “AR”, “BR”, “CO”, “CR”, “EC”, and “MX” represent China, Korea, India, Vietnam, Thailand, Malaysia, Côte d'Ivoire, Benin, Ethiopia, Argentina, Colombia, Costa Rica, Ecuador, Brazil, and Mexico, respectively. The unit for OC is μg m^{-3}.

Region	Country	Lon	Lat	Start	End	OC	Reference
Asia	CN	118.75	32.06	2018/1	2018/12	6.1	Xie et al. (2022)
Asia	CN	120.98	31.09	2018/1	2018/12	5.8	M. Wang et al. (2022)
Asia	CN	114.21	30.31	2017/3	2018/2	8.9	Huang et al. (2019)
Asia	CN	104.07	30.63	2019/1	2019/12	9.3	X. Xu et al. (2021)
Asia	CN	106.50	29.62	2019/11	2020/10	9.0	Ding et al. (2022)
Asia	CN	118.08	24.45	2017/1	2018/1	5.5	Wu et al. (2020)
Asia	CN	112.47	23.06	2019/1	2019/12	5.9	Lu et al. (2021)
Asia	CN	112.93	22.71	2019/1	2019/12	4.9	Lu et al. (2021)
Asia	CN	114.11	22.37	2017/1	2017/12	6.3	Chow et al. (2022)
Asia	CN	111.76	40.82	2019/10	2020/10	7.6	P. Liu et al. (2023)
Asia	CN	103.87	36.05	2019/12	2020/11	8.0	Wang et al. (2021)
Asia	CN	120.63	31.29	2020/1	2020/12	6.4	Y. e. Li et al. (2022)
Asia	CN	113.79	23.02	2019/1	2019/12	6.4	Tao et al. (2023)
Asia	KR	127.41	37.61	2018/1	2018/12	4.2	Park et al. (2022)
Asia	KR	126.94	37.61	2018/1	2018/12	4.2	Park et al. (2022)
Asia	KR	126.85	35.23	2018/1	2018/12	3.9	Park et al. (2022)
Asia	KR	124.63	37.97	2018/1	2018/12	2.1	Park et al. (2022)
Asia	KR	129.32	35.58	2018/1	2018/12	3.1	Park et al. (2022)
Asia	KR	126.39	33.35	2018/1	2018/12	1.9	Park et al. (2022)
Asia	KR	127.74	37.87	2018/2	2019/1	4.1	Choi et al. (2022)
Asia	KR	126.83	37.32	2021/1	2021/12	3.7	Hwang et al. (2023)
Asia	KR	126.49	36.78	2021/1	2021/12	4.6	Hwang et al. (2023)
Asia	KR	124.63	37.97	2019/1	2019/12	2.0	Afzal et al. (2025)
Asia	IN	75.46	29.10	2018/1	2018/12	18.9	Bhowmik et al. (2021)
Asia	IN	77.17	28.63	2018/1	2018/12	21.6	Bhowmik et al. (2021)
Asia	IN	77.28	28.45	2018/1	2018/12	16.0	Bhowmik et al. (2021)
Asia	IN	80.23	26.51	2018/1	2018/12	18.9	Bhowmik et al. (2021)
Asia	IN	77.17	28.63	2018/1	2018/12	13.4	Sharma et al. (2022)
Asia	IN	77.34	28.50	2016/12	2017/12	14.8	Shivani et al. (2019)
Asia	IN	88.27	27.04	2018/8	2019/6	3.6	Rai et al. (2021)
Asia	IN	77.41	23.26	2019/1	2019/12	9.5	Yadav et al. (2022)
Asia	IN	76.61	12.31	2019/1	2019/12	4.5	Yadav et al. (2022)
Asia	IN	88.39	22.84	2019/1	2019/12	11.3	Mukherjee et al. (2023)
Asia	IN	85.70	23.68	2019/1	2019/12	14.8	Pullokaran et al. (2024)
Asia	IN	94.16	26.74	2019/1	2019/12	7.9	Qadri et al. (2024)
Asia	IN	76.80	28.21	2016/12	2017/12	12.1	Shivani et al. (2019)
Asia	VN	105.80	21.01	2019/8	2020/8	10.3	Makkonen et al. (2023)
Asia	VN	106.68	10.76	2019/9	2020/8	8.8	Tran et al. (2023)
Asia	TH	100.50	7.01	2018/1	2018/12	2.1	Phairuang et al. (2020)
Asia	TH	98.35	7.89	2017/3	2018/2	3.1	ChooChuay et al. (2020)
Asia	TH	98.96	18.80	2021/1	2021/12	11.3	Santijitpakdee et al. (2024)

Asia	TH	101.24	6.88	2019/5	2020/2	2.1	Chaisongkaew et al. (2023)
Asia	MY	101.70	3.17	2017/2	2017/12	2.7	Jamhari et al. (2022)
Africa	CI	-3.99	5.35	2019/1	2019/12	4.0	Gnamien et al. (2023)
Africa	CI	-5.63	9.43	2019/1	2019/12	6.3	Gnamien et al. (2023)
Africa	BJ	2.43	2.35	2016/3	2017/3	8.5	Djossou et al. (2018)
Africa	ET	38.75	9.02	2015/12	2016/11	17.0	Tefera et al. (2020)
Latin America	AR	-58.51	-34.57	2019/4	2020/3	5.2	Dawidowski et al. (2024)
Latin America	BR	-75.61	6.24	2019/4	2020/3	7.4	Dawidowski et al. (2024)
Latin America	CO	-84.09	9.93	2019/5	2020/4	5.1	Dawidowski et al. (2024)
Latin America	CR	-78.51	-0.22	2019/4	2020/3	4.3	Dawidowski et al. (2024)
Latin America	EC	-46.73	-23.56	2019/4	2019/12	5.5	Dawidowski et al. (2024)
Latin America	MX	-99.15	19.48	2019/4	2020/3	6.3	Dawidowski et al. (2024)
Latin America	MX	-99.22	18.93	2016/7	2017/6	7.5	Valle-Hernández et al. (2024)

Table S6. List of the observed campaign-mean mass concentrations of OA, POA, POA_{exCOA} (POA exclude COA) and OOA as well as site locations for North America. The observed POA and OOA concentrations were derived from positive matrix factorization (PMF) analysis on online measurements by aerosol mass spectrometers. The units for OA, POA, POA_{exCOA}, and OOA are μg m^{-3}. "US" and "CA" represent the United States and Canada, respectively.

Country	Lon	Lat	Start	End	OA	POA	POA_{exCOA}	OOA	Reference
US	-117.49	34.10	2015/7/9	2015/7/28	4.24	1.01	0.42	3.23	Chen et al. (2018)
US	-119.77	36.79	2018/10/16	2018/11/30	11.11	3.06	3.06	8.05	Sun et al. (2022)
US	-119.77	36.79	2018/12/1	2019/2/28	8.82	3.19	3.19	5.62	Sun et al. (2022)
US	-119.77	36.79	2019/3/1	2019/5/4	4.27	0.61	0.61	3.66	Sun et al. (2022)
US	-84.41	33.77	2017/7/19	2017/8/25	6.40	1.14	0.66	5.26	F. Liu et al. (2023)
US	-84.41	33.77	2018/1/15	2018/2/11	3.89	1.96	1.39	1.93	F. Liu et al. (2023)
US	-85.04	33.93	2016/8/18	2016/10/11	5.00	0.00	0.00	5.00	Y. Chen et al. (2020)
US	-84.78	45.55	2016/7/1	2016/7/31	1.90	0.00	0.00	1.90	Bui et al. (2021)
US	-73.14	40.96	2018/6/25	2018/8/9	5.59	0.57	0.57	5.02	Zhang et al. (2022)
US	-73.95	40.82	2022/7/8	2022/8/7	4.41	1.15	0.47	3.26	Hass-Mitchell et al. (2024)
US	-73.82	40.74	2022/7/8	2022/8/7	4.45	1.00	0.44	3.44	Hass-Mitchell et al. (2024)
US	-97.48	36.60	2016/4/24	2016/5/20	2.39	0.48	0.48	1.91	Liu et al. (2021)
US	-97.48	36.60	2016/8/28	2016/9/24	3.88	0.50	0.50	3.39	Liu et al. (2021)
US	-75.19	39.96	2016/1/31	2016/3/2	3.23	1.38	0.69	1.85	Avery et al. (2019)
US	-75.19	39.96	2016/7/13	2016/8/13	5.87	2.15	0.46	3.72	Avery et al. (2019)
US	-97.73	30.39	2018/6/2	2018/6/28	2.50	0.00	0.00	2.50	Patel et al. (2020)
US	-95.25	29.72	2015/2/7	2015/2/27	5.51	2.91	2.44	2.60	Wallace et al. (2018)
US	-95.25	29.73	2015/5/13	2015/5/29	1.14	0.25	0.25	0.89	Al-Naiema et al. (2018)
US	-97.08	27.80	2021/4/2	2021/4/22	6.08	0.91	0.91	5.16	Zhou et al. (2023)
US	-98.48	29.37	2017/5/2	2017/5/26	5.86	0.82	0.82	5.04	Guo et al. (2024)
CA	-79.4	43.66	2016/5/10	2016/8/31	6.01	2.11	0.71	3.9	Jeong et al. (2019)

Table S7. Same as Table S6, but for Europe. "IN", "NL", "DE", "FI", "LT", "ES", "IT", and "GR" represent Ireland, Netherlands, Germany, Finland, Lithuania, Spain, Italy, and Greece, respectively.

Country	Lon	Lat	Start	End	OA	POA	POA_{exCOA}	SOA	Reference
IE	-7.91	53.10	2015/12/2	2015/12/29	2.90	1.89	1.89	1.02	Lin et al. (2019)
IE	-9.06	53.28	2016/2/5	2016/2/29	1.98	1.12	1.12	0.86	Lin et al. (2022)
IE	-9.06	53.28	2016/3/1	2016/5/31	2.05	0.70	0.70	1.35	Lin et al. (2022)
IE	-9.06	53.28	2016/6/1	2016/7/31	0.92	0.16	0.10	0.76	Lin et al. (2022)
NL	4.926	51.97	2021/5/11	2021/5/31	2.49	0.54	0.54	1.94	Nursanto et al. (2023)
NL	4.926	51.97	2021/6/1	2021/6/22	6.35	0.43	0.43	5.92	Nursanto et al. (2023)
NL	4.926	51.97	2021/9/1	2021/9/30	2.18	0.31	0.31	1.87	Nursanto et al. (2023)
DE	6.41	50.91	2019/1/15	2019/2/10	0.41	0.11	0.11	0.30	Liu et al. (2024)
DE	6.41	50.91	2019/4/8	2019/5/5	1.08	0.26	0.26	0.82	Liu et al. (2024)
DE	6.41	50.91	2019/8/7	2019/9/1	3.49	0.14	0.14	3.35	Liu et al. (2024)
DE	6.41	50.91	2019/11/11	2019/11/24	2.06	1.12	1.12	0.94	Liu et al. (2024)
DE	8.42	49.01	2019/6/28	2019/7/29	3.11	0.55	0.18	2.56	Song et al. (2022)
DE	8.42	49.01	2020/2/21	2020/3/31	3.36	1.75	1.21	1.61	Song et al. (2022)
FI	27.65	62.90	2020/9/15	2020/11/24	2.35	0.14	0.14	2.20	Kommula et al. (2024)
LT	25.18	54.64	2017/5/11	2017/6/14	6.35	1.78	1.78	4.57	Pauraite et al. (2018)
LT	25.32	54.72	2021/10/8	2021/11/12	7.32	4.88	4.88	2.44	Pauraite et al. (2023)
ES	-3.39	37.1	2021/6/8	2021/7/13	2.68	0.13	0.13	2.55	Rejano et al. (2024)
IT	12.5	41.88	2017/1/27	2017/2/28	7.49	1.87	0.94	5.62	Costabile et al. (2017)
GR	25.67	35.33	2016/5/9	2016/6/4	1.51	0.21	0.21	1.29	Florou et al. (2024)
GR	21.78	38.30	2019/2/28	2019/5/31	3.50	2.09	1.70	1.41	Manousakas et al. (2020)
GR	21.78	38.30	2019/6/1	2019/6/30	3.09	0.83	0.49	2.26	Manousakas et al. (2020)
GR	21.78	38.30	2018/10/25	2018/11/30	4.69	1.78	1.26	2.91	Manousakas et al. (2020)
GR	22.20	37.98	2021/9/1	2021/11/30	0.75	0.19	0.19	0.56	Zografou et al. (2024)

Table S8. Same as Table S6, but for Asia. "CN", "KR", and "IN" represent China, Korea, and India, respectively.

Country	Lon	Lat	Start	End	OA	POA	POA_{exCOA}	SOA	Reference
CN	114.36	34.84	2019/9/28	2019/11/1	6.80	1.50	0.80	5.20	Z. Li et al. (2021)
CN	111.71	34.79	2018/12/21	2019/1/21	17.92	5.91	5.91	12.01	Q. Wang et al. (2020)
CN	111.03	32.38	2018/5/29	2018/6/14	9.86	1.89	1.89	7.97	Ou et al. (2023)
CN	114.4	30.52	2019/10/3	2019/11/3	6.25	3.22	1.27	3.03	S. Li et al. (2022)
CN	116.33	39.73	2018/8/16	2018/9/16	12.24	3.79	3.79	8.44	T. Chen et al. (2020)
CN	116.33	39.73	2019/7/25	2019/8/21	9.30	2.90	2.90	6.42	T. Chen et al. (2021)
CN	116.31	39.99	2017/12/16	2018/1/10	13.30	5.45	4.12	7.98	Zheng et al. (2023)
CN	116.3	40	2019/1/18	2019/2/18	10.90	5.20	2.70	6.10	Hu et al. (2022)
CN	116.31	39.99	2018/3/13	2018/4/5	32.90	9.00	5.80	23.90	Zheng et al. (2023)
CN	116.37	39.97	2018/5/20	2018/6/23	12.70	3.70	1.70	9.10	W. Xu et al. (2021)
CN	116.37	39.97	2018/7/1	2018/8/5	13.20	1.70	1.70	11.30	Z. J. Li et al. (2022)
CN	116.32	39.99	2015/8/15	2015/9/10	13.80	3.90	2.50	9.80	Duan et al. (2019)
CN	116.31	39.99	2016/9/3	2016/10/4	22.00	6.00	3.00	16.00	Zheng et al. (2023)
CN	116.37	39.97	2018/10/15	2018/11/30	20.50	5.90	2.20	14.60	Z. J. Li et al. (2022)
CN	116.37	39.97	2018/11/20	2018/12/25	15.10	8.60	4.90	6.20	W. Xu et al. (2021)
CN	117.15	40.18	2020/4/8	2020/6/1	11.75	1.75	1.75	9.95	Wu et al. (2022)
CN	118.97	37.75	2018/3/17	2018/4/12	7.90	2.60	2.60	5.20	Feng et al. (2023)
CN	115.73	39.15	2019/12/10	2020/1/13	23.10	10.40	10.40	10.90	W. Xu et al. (2021)
CN	114.5	36.57	2019/8/10	2019/9/17	19.60	6.10	2.40	14.50	Gu et al. (2023)
CN	119.4	35.18	2018/9/2	2018/9/29	8.32	0.67	0.67	7.65	Lei et al. (2020)
CN	119.4	35.18	2019/3/2	2019/3/29	15.66	2.19	2.19	13.31	Lei et al. (2020)
CN	116.96	39.8	2017/11/15	2018/2/1	24.00	18.24	18.24	6.00	Y. Wang et al. (2020)
CN	116.96	39.8	2017/10/3	2017/11/14	13.90	7.92	7.92	5.98	Wang et al. (2023)
CN	117.67	40.4	2019/11/25	2019/12/25	4.80	1.10	1.10	3.50	J. Li et al. (2021)
CN	117.67	40.4	2019/5/1	2019/5/31	4.50	0.70	0.70	4.00	J. Li et al. (2021)
CN	117.67	40.4	2019/6/20	2019/7/26	4.90	0.00	0.00	4.90	J. Li et al. (2021)
CN	117.67	40.4	2019/10/12	2019/11/12	4.50	0.60	0.60	4.00	J. Li et al. (2021)
CN	114.37	37.18	2016/4/30	2016/6/20	11.59	2.54	1.27	9.04	Y. Zhang et al. (2018)
CN	113.9	35.3	2017/6/8	2017/6/25	18.00	4.32	4.32	13.50	H. Li et al. (2018)
CN	113.92	35.28	2018/12/1	2019/1/15	22.58	10.29	10.29	12.28	C. Chen et al. (2021)
CN	107.14	34.35	2019/2/26	2019/3/27	16.02	6.41	4.17	9.61	Y. Wang et al. (2022)
CN	104.13	35.95	2018/12/4	2019/1/6	10.50	5.00	5.00	5.50	C. Tang et al. (2022)
CN	103.86	36.05	2020/1/14	2020/3/4	12.41	6.16	4.61	6.24	Xu et al. (2020)
CN	108.35	34.07	2019/12/23	2020/2/7	12.57	4.14	4.14	8.53	Zhong et al. (2021)
CN	109.02	34.34	2018/5/19	2018/6/18	7.50	1.51	0.46	5.30	Zhong et al. (2022)
CN	108.89	34.22	2019/6/22	2019/7/21	14.00	4.40	1.80	9.60	Duan et al. (2021)
CN	108.89	34.22	2018/12/4	2019/3/15	37.10	15.30	10.50	21.80	Duan et al. (2022)
CN	111.05	35.04	2020/11/1	2021/1/11	24.50	9.20	9.20	15.30	Y. Li et al. (2022)
CN	109.49	18.84	2015/3/18	2015/4/15	4.90	0.00	0.00	4.89	Zhu et al. (2016)
CN	117.02	23.42	2015/12/22	2016/1/16	7.06	2.61	2.61	4.45	Cao et al. (2019)
CN	118.05	24.6	2015/5/1	2015/5/18	13.07	3.61	3.61	9.46	Cao et al. (2017)
CN	118.05	24.6	2018/12/1	2018/12/22	8.42	2.39	2.39	6.05	Chen et al. (2022)
CN	118.05	24.6	2018/8/1	2018/8/22	7.89	1.60	1.60	6.30	Chen et al. (2022)
CN	113.37	23.15	2017/11/20	2018/1/5	17.30	5.36	2.25	12.11	Guo et al. (2020)
CN	113.36	23.14	2018/10/1	2018/11/20	14.70	5.30	3.10	9.70	W. Chen et al. (2021)
CN	113.33	23.06	2021/3/1	2021/5/31	11.44	4.05	1.20	7.39	Zhai et al. (2023)

CN	113.33	23.06	2021/6/1	2021/8/31	7.76	2.53	0.59	5.23	Zhai et al. (2023)
CN	114.18	22.3	2017/12/24	2018/1/15	6.80	2.35	1.12	4.45	Liu et al. (2019)
CN	114.17	22.32	2017/3/31	2017/4/20	14.00	5.50	5.50	8.30	Niu et al. (2021)
CN	114.253	22.209	2018/11/1	2018/11/30	5.39	0.73	0.73	4.65	Huo et al. (2024)
CN	114.253	22.209	2020/9/29	2020/11/18	6.27	0.74	0.74	5.54	Huo et al. (2024)
CN	113.9	22.6	2015/8/1	2015/8/31	10.00	2.97	2.97	7.03	Yu et al. (2019)
CN	113.9	22.6	2015/11/4	2015/11/30	7.80	2.76	2.76	5.04	Yu et al. (2019)
CN	113.9	22.6	2016/4/1	2016/4/30	4.30	1.81	1.81	2.49	Yu et al. (2019)
CN	113.9	22.6	2018/12/12	2019/1/3	9.60	4.60	2.40	5.00	Cao et al. (2022)
CN	113.9	22.6	2020/1/24	2020/2/24	8.67	1.93	1.93	6.75	M.-X. Tang et al. (2022)
CN	105.63	29.42	2021/1/25	2021/2/14	25.50	11.91	11.91	13.59	Zhang et al. (2023)
CN	104.42	30.93	2021/12/18	2022/1/22	39.20	17.80	17.80	20.23	Bao et al. (2023)
CN	105.63	29.42	2021/1/25	2021/2/14	25.50	11.91	11.91	13.59	Zhang et al. (2023)
CN	90.95	30.77	2015/5/31	2015/7/1	1.36	0.00	0.00	1.36	Xu et al. (2018)
CN	86.95	28.36	2016/4/12	2016/5/12	2.39	1.37	1.37	1.01	X. Zhang et al. (2018)
CN	100.9	36.28	2017/7/1	2017/7/31	3.14	0.79	0.79	2.35	Zhang et al. (2019)
CN	91.03	29.65	2019/8/31	2019/9/26	3.88	2.56	1.19	1.32	Xu et al. (2024)
CN	96.51	39.5	2020/8/4	2020/8/29	0.69	0.00	0.00	0.69	Xu et al. (2024)
CN	84.35	42.83	2021/8/29	2021/9/26	0.73	0.00	0.00	0.73	Xu et al. (2024)
CN	95.32	29.3	2021/3/26	2021/5/22	3.25	0.53	0.53	2.72	Xu et al. (2024)
CN	119.96	31.76	2020/11/3	2020/11/20	13.00	4.68	2.60	8.19	Zhu et al. (2024)
CN	120.21	30.21	2016/8/5	2016/8/21	17.00	6.70	3.50	10.70	K. Li et al. (2018)
CN	120.21	30.21	2016/9/7	2016/9/23	18.50	6.10	2.00	12.10	K. Li et al. (2018)
CN	118.73	32.01	2015/4/13	2015/4/29	12.69	5.64	3.50	7.04	Wang et al. (2016)
CN	118.75	32.04	2015/10/20	2015/11/19	25.20	7.06	7.06	18.14	Zhang et al. (2017)
CN	118.95	32.12	2019/7/4	2019/7/31	10.10	2.18	2.18	7.92	Ge et al. (2022)
CN	118.95	32.12	2019/10/2	2019/10/27	10.90	4.95	4.95	5.95	Ge et al. (2022)
CN	118.95	32.12	2019/12/4	2019/12/28	18.00	9.94	9.94	8.06	Ge et al. (2022)
CN	118.95	32.12	2020/4/2	2020/4/30	11.30	4.91	4.91	6.39	Ge et al. (2022)
CN	118.86	31.92	2021/7/18	2021/8/26	13.08	3.96	1.82	9.12	Xian et al. (2023)
CN	121.90	29.75	2018/1/23	2018/2/24	3.81	0.84	0.84	2.97	Huang et al. (2021)
CN	120.99	31.10	2015/7/1	2015/8/31	9.48	2.79	2.79	6.77	Zhao et al. (2020)
CN	120.99	31.10	2015/9/1	2015/11/30	13.22	3.79	3.79	9.43	Zhao et al. (2020)
CN	120.99	31.10	2015/12/1	2016/2/29	18.09	4.76	4.76	13.04	Zhao et al. (2020)
CN	120.99	31.10	2016/3/1	2016/5/31	12.44	2.80	2.80	9.78	Zhao et al. (2020)
CN	120.99	31.10	2016/6/1	2016/6/30	10.87	2.65	2.65	8.32	Zhao et al. (2020)
CN	121.43	31.17	2016/11/28	2017/1/13	13.00	6.40	2.20	6.60	Zhu et al. (2021)
CN	121.43	31.17	2016/8/23	2016/9/10	13.80	5.40	2.10	8.40	Zhu et al. (2021)
CN	121.43	31.17	2017/5/18	2017/6/4	9.80	5.30	2.60	4.50	Zhu et al. (2021)
CN	121.43	31.17	2018/10/31	2018/12/2	9.44	4.80	1.90	4.65	Cui et al. (2022)
CN	121.4	31.2	2018/1/10	2018/1/21	24.42	7.82	7.82	16.61	Qian et al. (2023)
KR	127.55	38.02	2018/3/9	2018/3/29	14.24	3.67	3.67	10.57	Song et al. (2021)
KR	127.55	38.02	2018/9/5	2018/9/15	3.50	1.05	1.05	2.45	Song et al. (2021)
KR	127.55	38.02	2018/1/4	2018/2/20	9.04	2.59	2.59	6.45	Song et al. (2021)
KR	127.05	37.6	2015/12/5	2016/1/21	12.10	7.14	4.72	4.96	Kim et al. (2017)
KR	127.05	37.6	2016/4/14	2016/6/15	9.72	3.79	1.65	5.93	Kim et al. (2018)
KR	127.05	37.6	2017/1/1	2017/2/10	13.63	6.17	3.99	7.46	Kim et al. (2022)
KR	127.05	37.6	2019/2/22	2019/4/2	13.69	3.29	1.23	10.41	Kim et al. (2020)

KR	127.05	37.60	2019/6/12	2019/7/16	5.69	1.21	0.31	4.48	Hu et al. (2024)
IN	72.6	23	2017/9/19	2017/10/20	9.00	3.78	3.78	5.22	Singh et al. (2019)
IN	72.6	23	2020/6/1	2020/6/16	3.80	0.84	0.84	2.96	Dave et al. (2021)
IN	72.6	23	2020/2/29	2020/3/23	8.60	3.10	3.10	5.50	Dave et al. (2021)
IN	73.65	17.92	2016/6/1	2016/9/30	1.52	1.21	1.21	0.31	Mukherjee et al. (2018)
IN	73.65	17.92	2016/3/17	2016/5/27	6.30	3.15	3.15	3.15	Mukherjee et al. (2018)
IN	73.65	17.92	2016/12/1	2017/2/28	7.02	3.44	3.44	3.58	Mukherjee et al. (2018)
IN	73.65	17.92	2021/2/6	2021/2/26	10.51	2.63	2.63	7.88	Mukherjee et al. (2025)
IN	73.65	17.92	2016/10/1	2016/11/30	2.57	0.83	0.83	1.74	Mukherjee et al. (2018)
IN	73.81	18.54	2020/12/1	2021/2/28	22.10	9.06	9.06	13.04	Vispute et al. (2025)
IN	73.81	18.54	2020/10/1	2020/11/30	7.80	3.35	3.35	4.45	Vispute et al. (2025)
IN	73.81	18.54	2020/6/1	2020/9/30	2.40	0.86	0.86	1.54	Vispute et al. (2025)
IN	73.81	18.54	2020/3/10	2020/3/24	10.16	3.62	3.62	6.54	Acharja et al. (2022)
IN	77.28	28.45	2018/1/27	2018/3/15	32.43	14.45	14.45	17.98	Lalchandani et al. (2021)
IN	80.3	26.5	2015/5/24	2015/8/15	7.27	1.15	1.15	6.12	Chakraborty et al. (2016)
IN	85.8	20.2	2016/10/1	2016/11/30	5.98	2.15	2.15	3.83	Kompalli et al. (2023)
IN	77.17	28.62	2018/2/17	2018/3/15	55.00	28.60	28.60	26.40	Lalchandani et al. (2021)
IN	77.17	28.63	2019/11/1	2020/1/8	57.05	26.99	26.99	30.06	Lalchandani et al. (2022)
IN	77.19	28.54	2018/1/17	2018/3/11	65.30	31.34	31.34	33.96	Lalchandani et al. (2021)
IN	77.2	28.58	2018/2/16	2018/5/26	42.83	20.65	20.65	22.18	Tobler et al. (2020)
IN	77.19	28.54	2019/5/31	2019/7/26	12.18	4.40	3.50	7.78	Shukla et al. (2021)
IN	77.23	28.66	2018/8/3	2018/8/18	25.22	11.68	8.87	13.54	Cash et al. (2021)
IN	77.19	28.54	2017/7/1	2017/9/15	23.00	6.67	3.22	16.33	Bhandari et al. (2022)
IN	77.19	28.54	2019/9/25	2019/10/29	27.51	11.96	11.96	15.55	Lalchandani et al. (2022)
IN	77.22	28.59	2018/11/6	2018/11/20	73.23	39.69	39.69	33.54	Reyes-Villegas et al. (2021)
IN	77.19	28.54	2019/11/14	2020/1/8	50.52	33.87	33.87	16.65	Lalchandani et al. (2022)

Table S9. Global budgets for OA, POA, and SOA for the year 2018 from the "WDLuo" simulation run.

	Net production ($Tg\ yr^{-1}$)	Dry deposition ($Tg\ yr^{-1}$)	Wet deposition ($Tg\ yr^{-1}$)	Burden (Tg)	Lifetime (days)
POA	23.0	3.5	19.5	0.3	5.2
SOA	105.6	9.5	96.1	1.4	4.6
OA	128.6	13.0	115.6	1.7	4.7

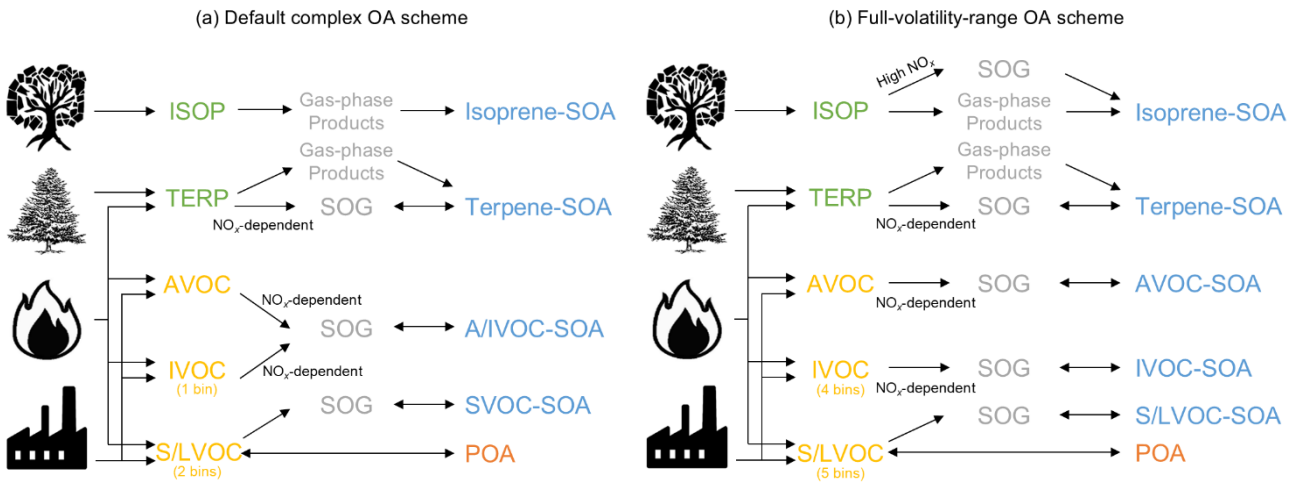

Figure S1. The schematics of the (a) default complex OA and (b) full-volatility-range OA schemes.

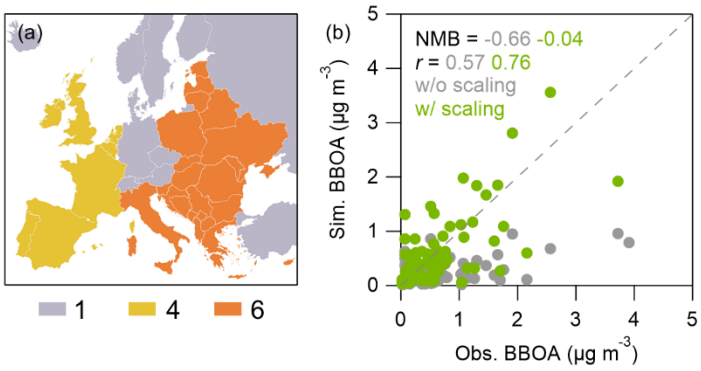

Figure S2. (a) Empirical scalars for modifying S/LVOC emissions from residential biofuel combustion in different European countries. (b) Scatterplots of the observed-derived and simulated concentrations of BBOA in Europe without and with scaling S/LVOC emissions from residential biofuel combustion.

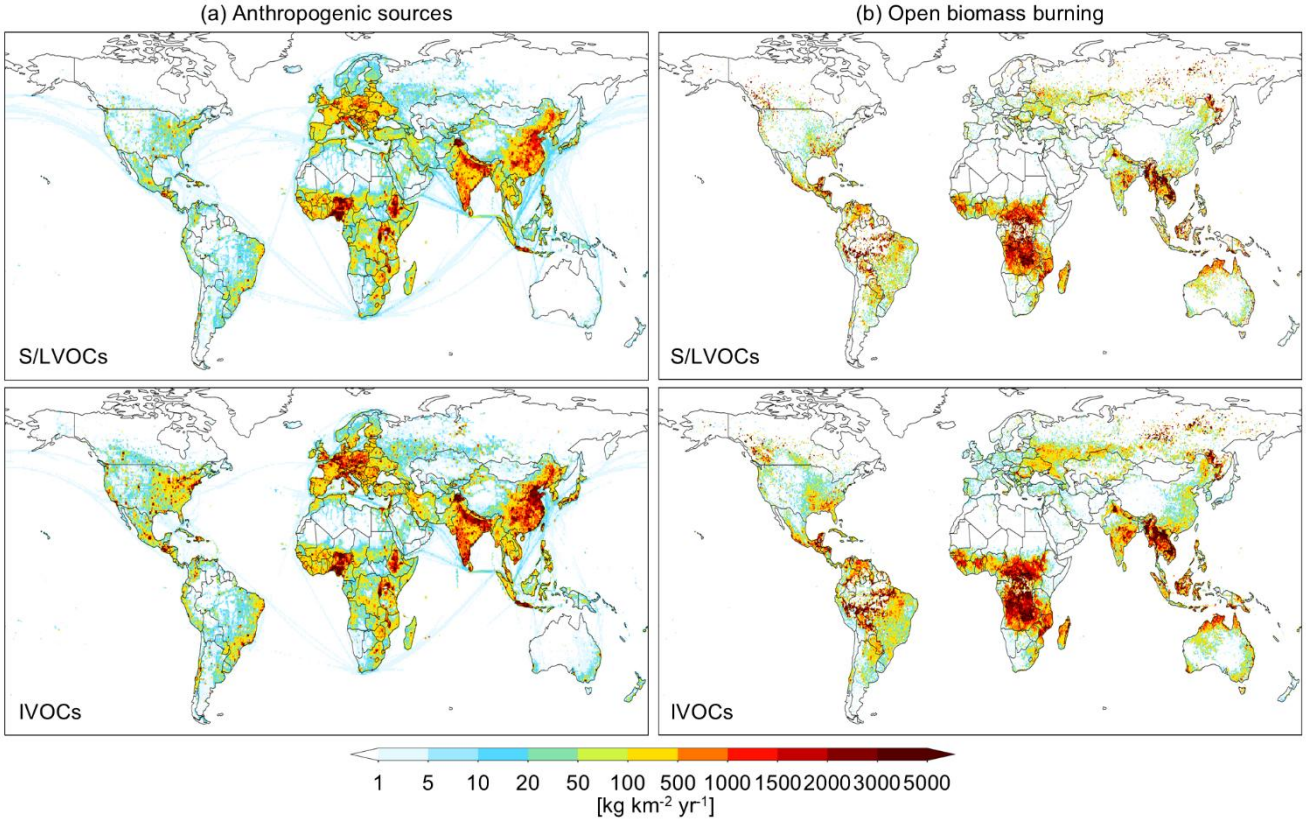

Figure S3. Annual emissions of S/LVOCs and IVOCs from (a) anthropogenic sources and (b) open biomass burning in the year 2018 ("Base").

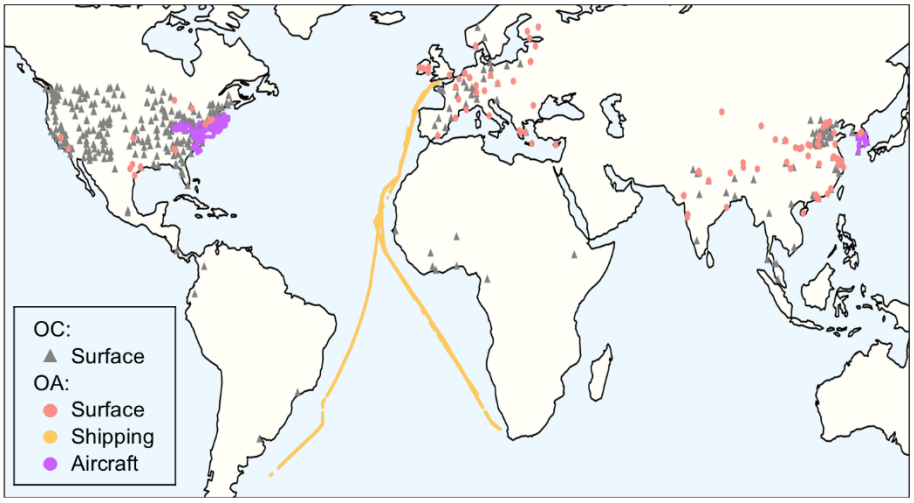

Figure S4. Locations of surface OC and OA measurements and tracks of the shipborne and airborne field campaigns for OA. The OC measurements in the US are adopted from the Interagency Monitoring of Protected Visual Environments (IMPROVE) and the Chemical Speciation Network (CSN) for the year of 2018, which are downloaded from http://views.cira.colostate.edu/fed/. The OC measurements in the Europe are provided by EBAS (https://ebas-data.nilu.no/) from 2016 to 2021. The OC measurements in the China are adopted from the China National Environmental Monitoring Centre (CNEMC) and other research sites from 2017 to 2020 (Chen et al., 2024). The International Network to study Deposition and Atmospheric composition in Africa (INDAAF) also provides the OC measurements in Africa from 2018 to 2019 (https://indaaf.obs-mip.fr/).

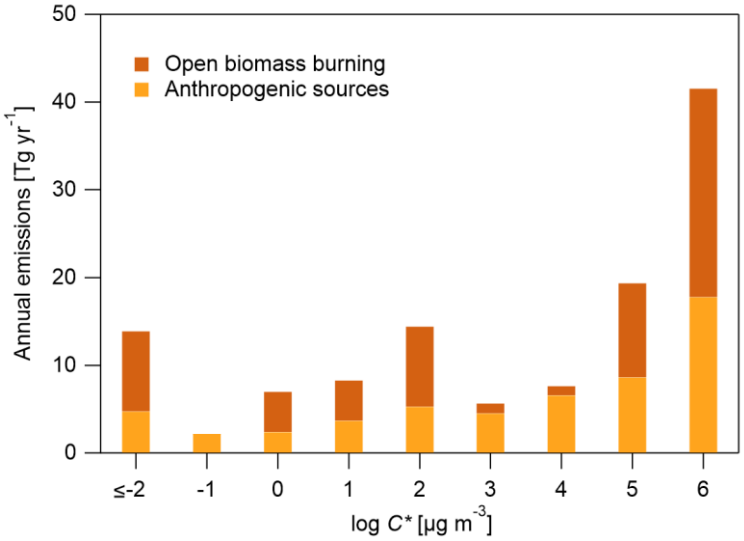

Figure S5. Global emissions of S/LVOCs and IVOCs from anthropogenic sources and open biomass burning in each volatility bin.

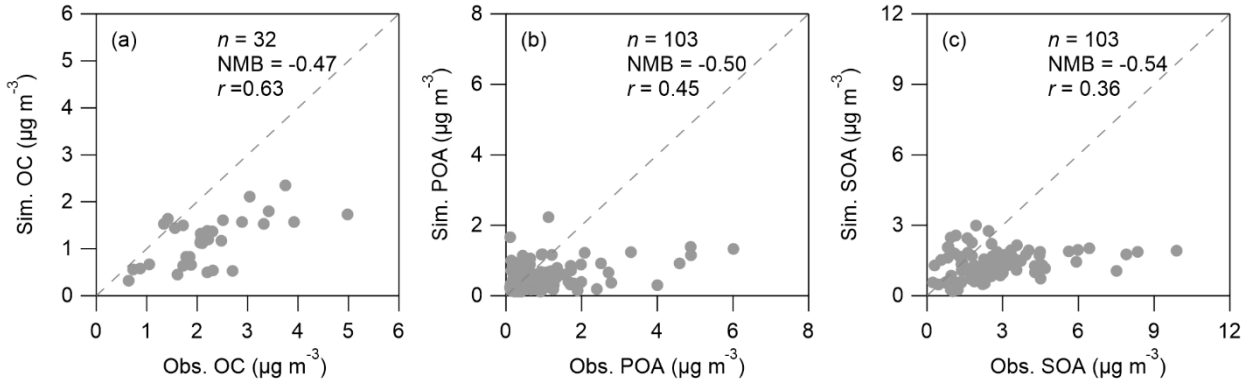

Figure S6. Scatterplots of the observed-derived and simulated concentrations of (a-c) OC, POA, and SOA in Europe without the residential biofuel correction.

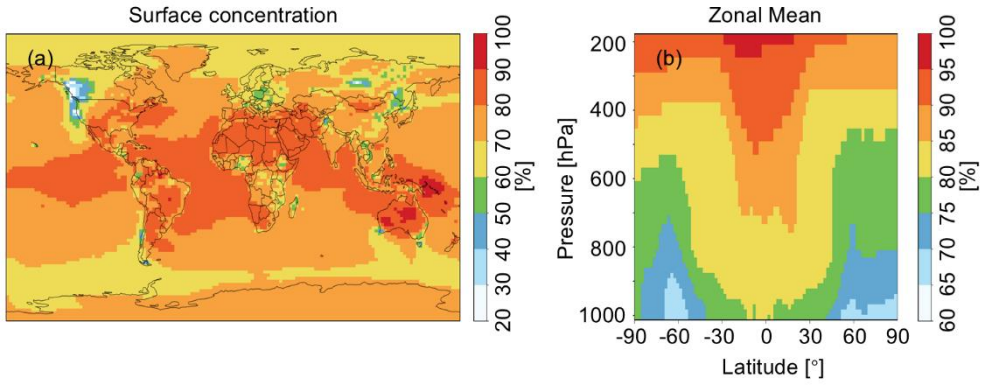

Figure S7. (a) Surface and (b) zonal mean annual-averaged fraction of SOA in OA.

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