

Supplemental Material

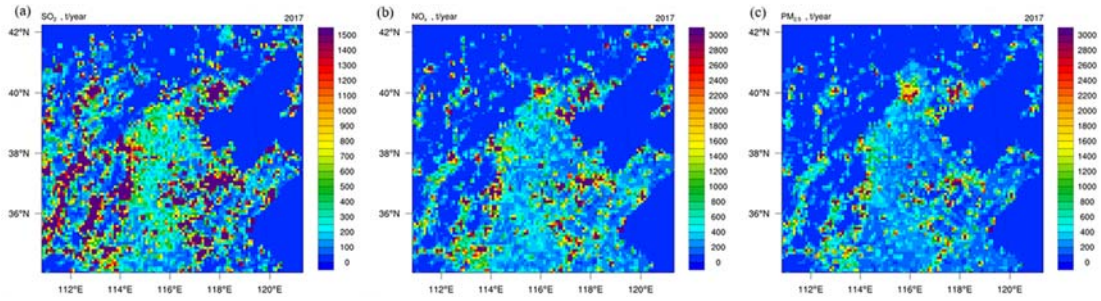


Fig. S1 Spatial distribution of annual (a) SO₂ emission, (b) NO_x emission and (c) PM_{2.5} emission in D2

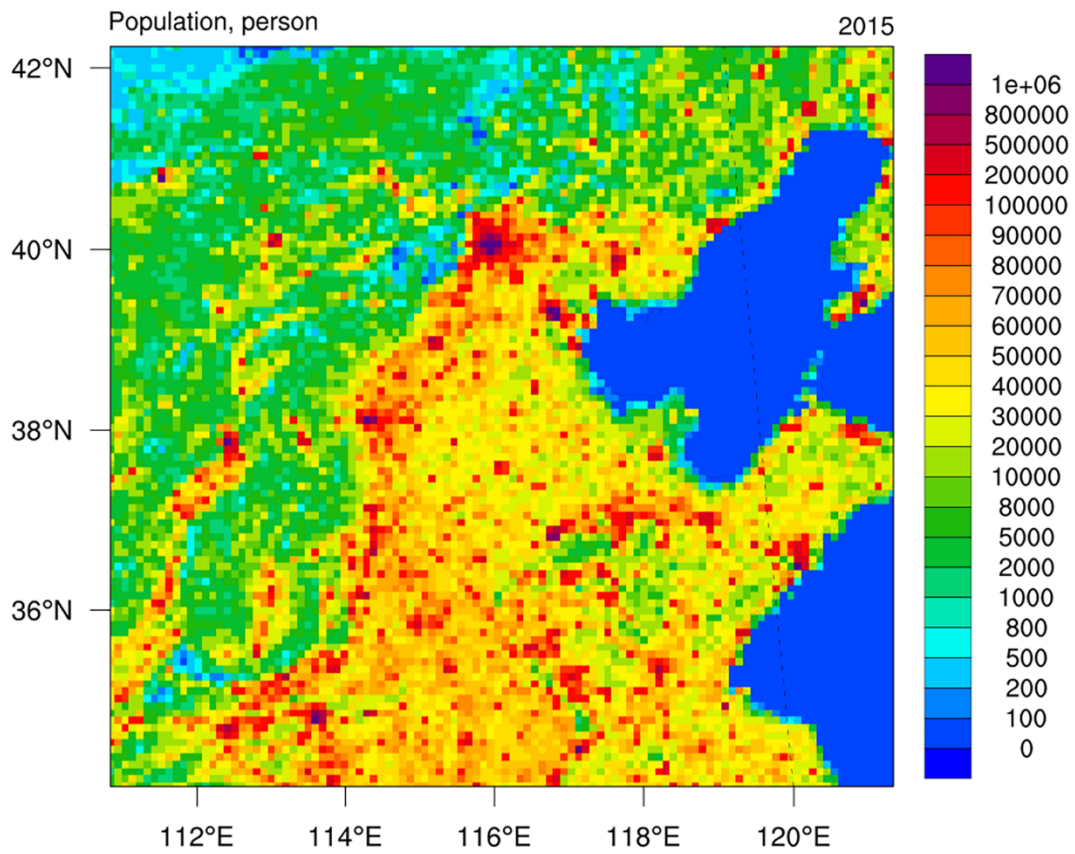


Fig. S2 Spatial distribution of population (D2)

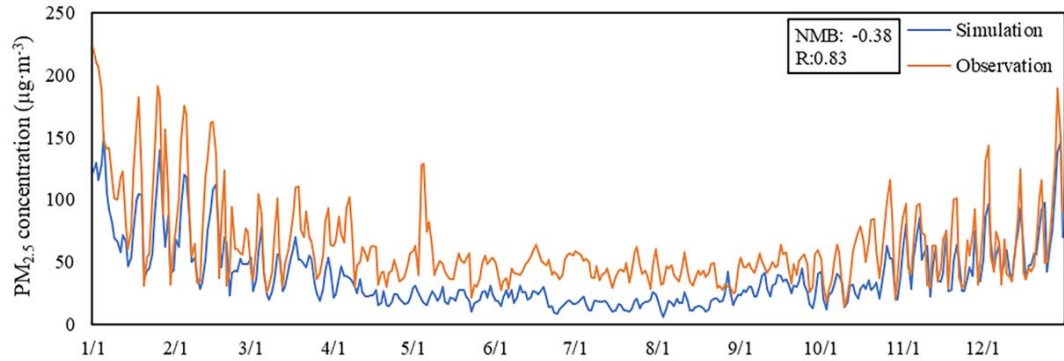


Fig. S3 Time series of the simulated and observed daily averaged $PM_{2.5}$ concentration (based on average of all sites in D2)

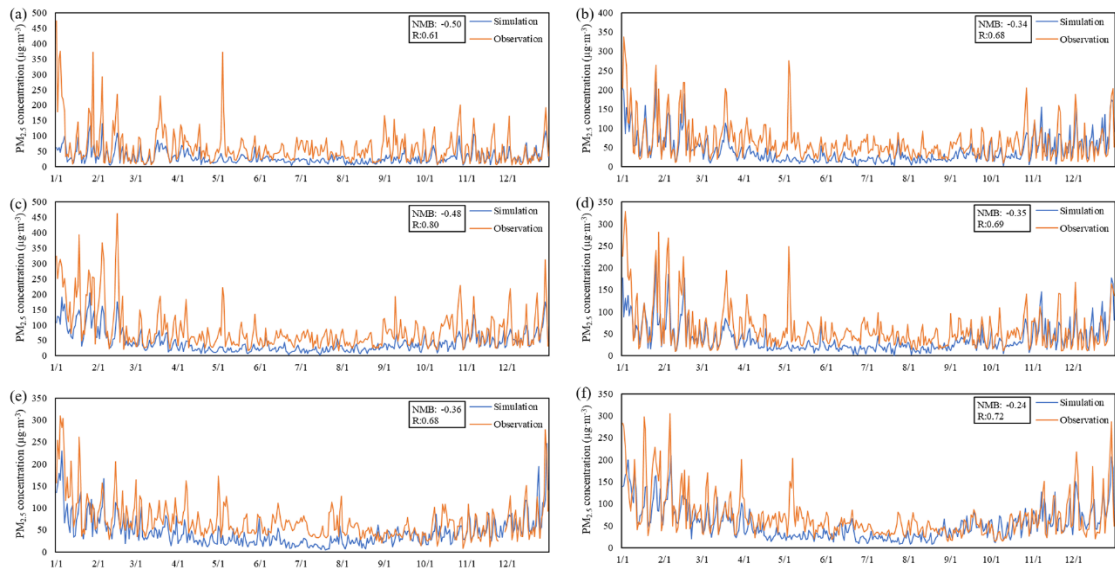


Fig. S4 Time series of the simulated and observed daily averaged $PM_{2.5}$ concentration at site (a) 1003A in Beijing, (b) 1015A in Tianjin, (c) 1029A in Shijiazhuang, (d) 1067A in Langfang, (e) 1305A in Jinan and (f) 1322A in Zhengzhou.

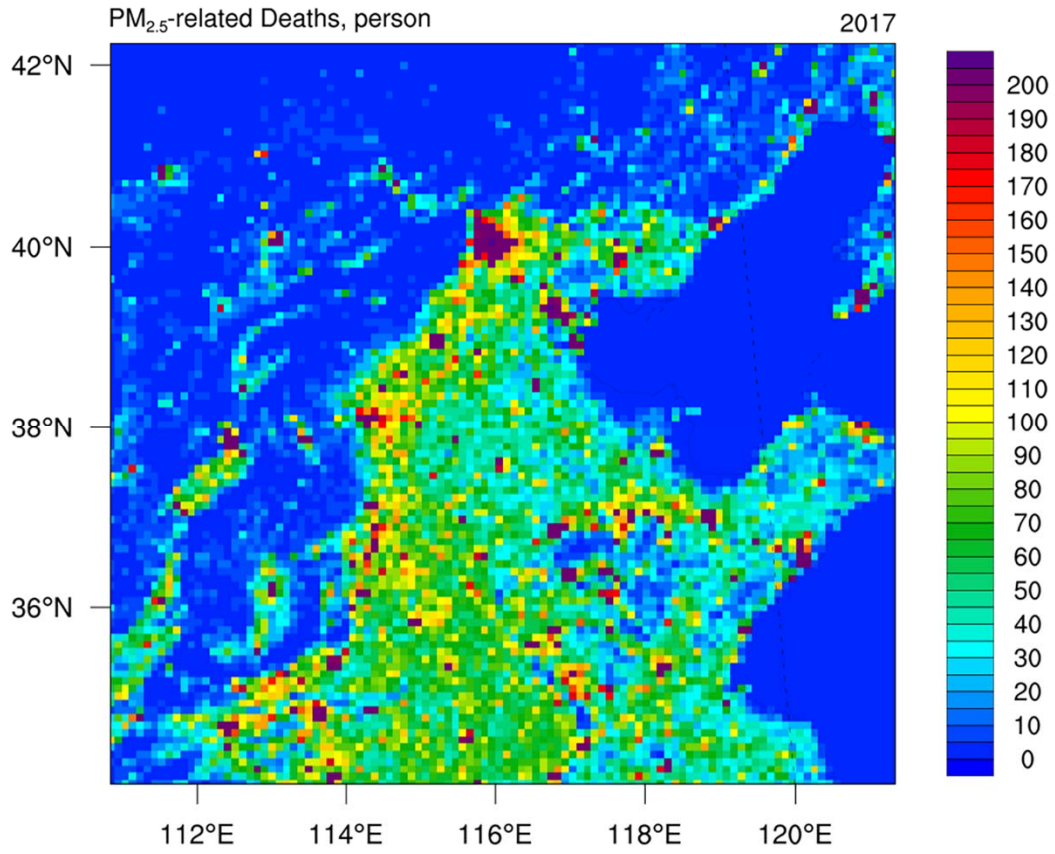


Fig. S5 Spatial distribution of PM_{2.5}-related deaths in 2017 (D2)

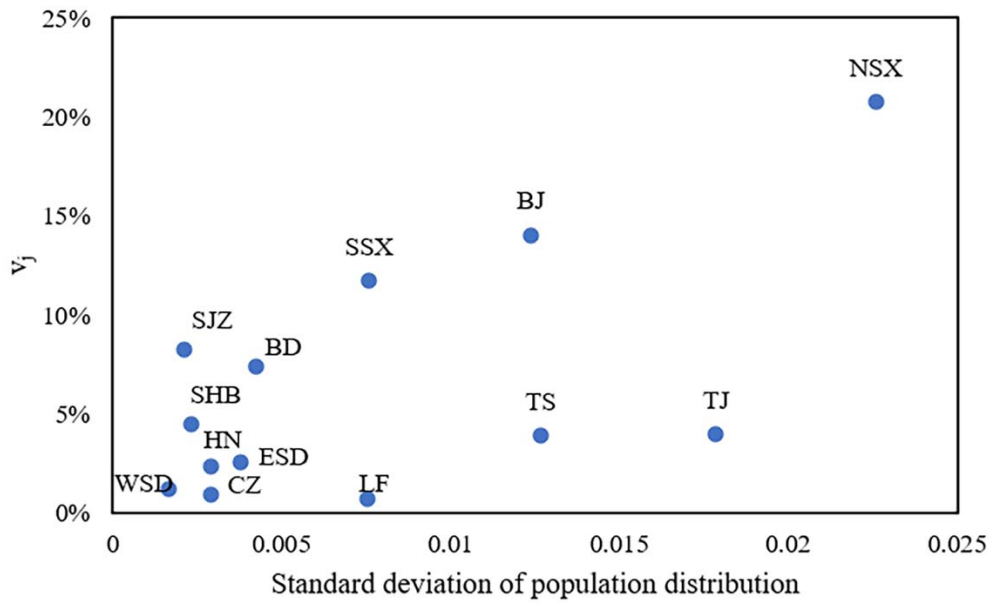


Fig. S6 Relevance between $\{v_j\}$ and standard deviation of population distribution in 13 regions

Table S1 Emissions of major pollutants in 13 tagged regions in 2017 (kt/yr)

Tag	City	PM _{2.5}	NO _x	SO ₂	NH ₃
BJ	Beijing	47	175	24	35
TJ	Tianjin	61	309	108	37
SJZ	Shijiazhuang	77	247	121	60
TS	Tangshan	114	389	210	58
LF	Langfang	22	70	26	29
BD	Baoding	81	200	173	88
CZ	Cangzhou	35	92	39	53
SHB	Total	174	493	268	150
	Hengshui	27	69	35	40
	Xingtai	54	142	77	46
	Handan	94	282	156	63
NSX	Total	47	142	184	17
	Taiyuan	33	98	109	13
	Yuanquan	14	43	74	4
SSX	Total	81	192	269	33
	Changzhi	40	102	141	14
	Jincheng	41	90	128	19
ESD	Total	182	577	358	144
	Binzhou	34	116	68	31
	Jinan	47	159	103	35
	Zibo	61	191	124	21
	Dezhou	39	110	63	58
WSD	Total	104	295	167	128
	Liaocheng	43	138	85	50
	Jining	15	45	31	11
	Heze	46	112	52	68
HN	Total	224	618	262	289
	Zhengzhou	54	193	71	46
	Kaifeng	19	50	17	55
	Anyang	44	103	48	43
	Hebi	17	39	21	21
	Xinxiang	36	87	40	56
	Jiaozuo	37	103	48	35
Puyang	17	44	17	33	

Table S2 Evaluation for meteorological field simulation

Month	Wind speed (m/s)				Wind direction (degree)				Temperature (K)				Absolute humidity (g/kg)			
	Observe	Predict	Bias	Gross Error	Observe	Predict	Bias	Gross Error	Observe	Predict	Bias	Gross Error	Observe	Predict	Bias	Gross Error
Jan	2.60	2.71	0.10	1.07	240.76	195.01	7.81	42.76	271.68	271.72	-0.18	1.46	2.72	2.61	-0.12	0.40
Apr	3.09	3.29	0.19	1.25	213.83	207.65	4.42	43.13	287.84	287.39	-0.64	1.88	5.92	5.56	-0.37	0.99
Jul	2.67	2.68	0.01	1.12	165.60	147.85	-0.29	46.82	300.44	299.74	-0.80	1.95	17.23	16.35	-0.91	2.34
Oct	2.56	2.73	0.16	1.02	202.82	132.28	6.88	43.06	285.69	286.19	0.37	1.25	7.37	7.00	-0.40	0.86

Notes: The criteria for bias of wind speed, wind direction, temperature and absolute humidity are $\leq \pm 0.5$ m/s, $\leq \pm 10$ deg, $\leq \pm 0.5$ K and $\leq \pm 1$ g/kg respectively. The criteria for gross error of wind speed, wind direction, temperature and absolute humidity are ≤ 2 m/s, ≤ 30 deg, ≤ 2 K and ≤ 2 g/kg respectively

Table S3 Verification for PM_{2.5} components simulation (Chegongzhuang Station, Beijing, China)

Components	Observation ($\mu\text{g}/\text{m}^3$)	Simulation ($\mu\text{g}/\text{m}^3$)	NMB (%)	NME (%)
PM _{2.5}	59.0	32.6	-44.75	53.51
PM _{2.5} -EC	2.5	2.0	-20.00	43.93
PM _{2.5} -NH ₄ ⁺	6.6	2.4	-63.64	68.75
PM _{2.5} -NO ₃ ⁻	12.2	5.7	-53.28	66.68
PM _{2.5} -SO ₄ ²⁻	8.7	2.7	-68.97	70.87
PM _{2.5} -OC	11.8	6.4	-45.76	38.87
PM _{2.5} -OTHER ^{a)}	17.2	13.4	-22.09	54.43

Notes: a) PM_{2.5}-OTHER equals to PM_{2.5} minus other components in this table

Table S4 Comparison of local emissions contribution in Beijing with previous studies

Studies	Method	Simulation period	Local emissions contribution
Lang et al. (2013)	CMAQ-BFM	2010 (1,4,7,10)	55.4% (urban)
Li et al. (2015)	CAMx-PSAT	2013 (1,4,7,10)	52.0% (urban)
Chang et al. (2019)	CMAQ-ISAM	2014 (1,3,7,10)	54.1% (urban)
Dong et al. (2020)	CMAQ-ISAM	2017 (1,3,7,10)	49.7%(urban)
This Study	CMAQ-ISAM	2017 (1-12)	54.1% (urban) 36.9% (the whole Beijing)

Table S5 Estimated number of PM_{2.5}-related deaths and deaths per square kilometer in divided regions (95% confidence intervals)

Region/City ^{a)}	Deaths (in thousands)	Deaths per square kilometer
HN	42.24 (20.94,84.28)	1.05 (0.52,2.09)
SHB	28.17 (14.39,55.99)	0.85 (0.43,1.68)
ESD	27.74 (13.74,55.36)	0.85 (0.42,1.70)
WSD	25.24 (12.44,50.41)	0.74 (0.37,1.48)
BJ	23.37 (11.43,46.68)	1.42 (0.70,2.84)
TJ	15.54 (7.65,31.02)	1.30 (0.64,2.60)
BD	14.26 (7.14,28.42)	0.64 (0.32,1.28)
SJZ	13.57 (6.92,26.98)	1.04 (0.53,2.07)
CZ	9.21 (4.60,18.36)	0.66 (0.33,1.31)
TS	9.00 (4.36,18.00)	0.67 (0.32, 1.34)
NSX	6.74 (3.28,13.47)	0.58 (0.28,1.17)
SSX	6.33 (3.01,12.68)	0.27 (0.13,0.54)
LF	5.59 (2.78,11.15)	0.88 (0.43,1.75)

Notes: a) The order of regions is arranged according to the number of total deaths