Supplemental Material

Effects of air pollution control policies on PM$_{2.5}$ pollution improvement in China from 2005 to 2017: a satellite based perspective

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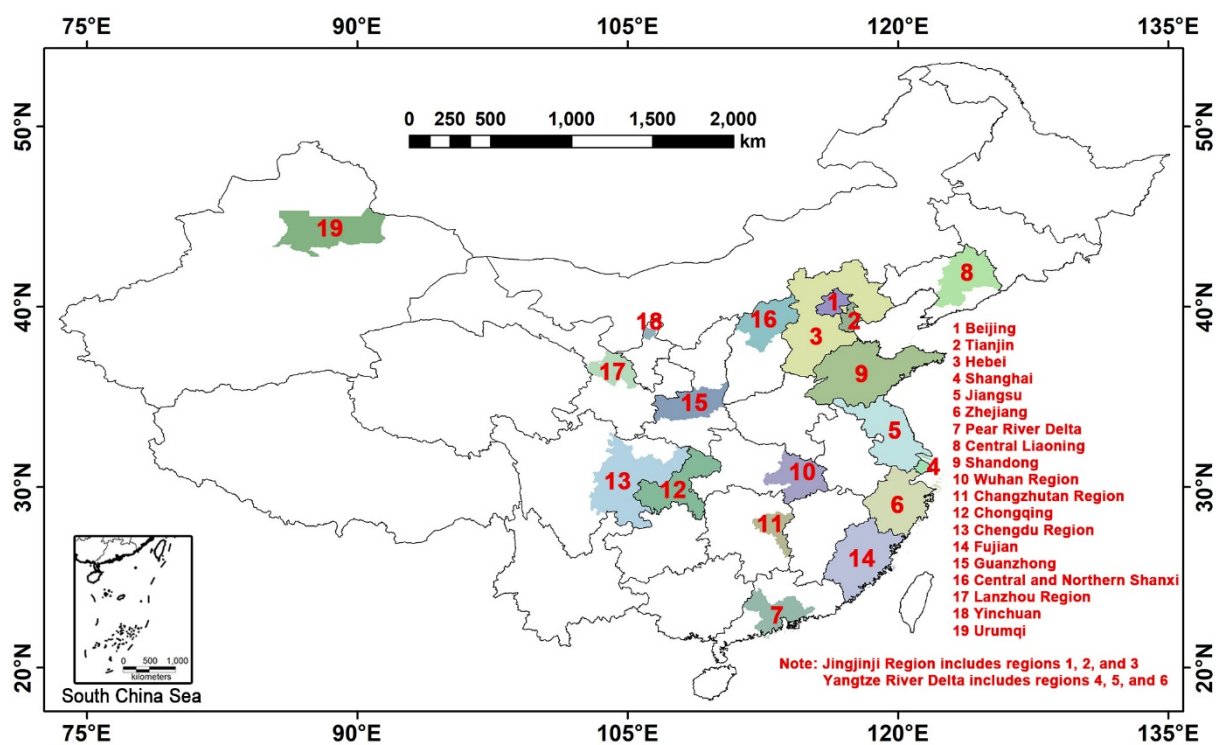
Figure S1. Key regions in 12th Five Year Plan on Air Pollution Prevention and Control in Key Regions

Table S1 Summary statistics of variables for the modeling dataset from 2014 to 2017

Year	Variables [a]	Min	Max	Median	Mean	S.D.
2014 (N=95,649)	$PM_{2.5}$ (μg/m³)	0.50	517.00	53.45	65.66	47.84
	AOD (unitless)	-0.01	4.51	0.50	0.67	0.61
	WS (m/s)	0.02	18.72	3.82	4.25	2.35
	PBLH (100m)	0.61	52.93	16.22	17.07	5.86
	PS (hPa)	589.22	1037.16	1001.92	980.71	55.83
	RH_PBLH (%)	7.93	96.46	49.05	49.93	18.22
	Precip_Lag1 (mm)	0.00	200.72	0.01	1.29	5.69
	Fire_spots (counts)	0.00	462.00	0.00	2.97	10.64
	ForestCover (%)	0.00	92.52	3.75	13.10	18.74
	UrbanCover (%)	0.00	100.00	22.17	27.48	22.68
2015 (N=110,805)	$PM_{2.5}$ (μg/m³)	0.50	417.99	43.64	54.02	39.32
	AOD (unitless)	-0.05	4.16	0.44	0.58	0.54
	WS (m/s)	0.03	18.45	3.53	3.97	2.28
	PBLH (100m)	0.63	49.78	15.26	16.05	6.30
	PS (hPa)	558.24	1038.16	996.03	964.45	72.78
	RH_PBLH (%)	5.30	98.81	51.37	51.75	17.74
	Precip_Lag1 (mm)	0.00	283.99	0.02	1.71	6.83
	Fire_spots (counts)	0.00	688.00	0.00	2.58	11.29
	ForestCover (%)	0.00	97.60	4.55	14.23	19.61
	UrbanCover (%)	0.00	100.00	19.19	24.23	21.10
2016 (N=113,490)	$PM_{2.5}$ (μg/m³)	1.00	520.61	40.00	50.65	38.55
	AOD (unitless)	-0.03	4.25	0.40	0.53	0.48
	WS (m/s)	0.04	15.25	3.43	3.81	2.11
	PBLH (100m)	0.71	52.44	14.13	15.04	6.45
	PS (hPa)	558.16	1042.00	995.34	964.64	72.06
	RH_PBLH (%)	4.86	96.48	52.39	52.56	17.13
	Precip_Lag1 (mm)	0.00	277.79	0.02	2.15	8.69
	Fire_spots (counts)	0.00	330.00	0.00	2.08	7.06
	ForestCover (%)	0.00	97.60	4.58	14.37	19.72
	UrbanCover (%)	0.00	100.00	19.20	24.36	21.24
2017 (N=123,652)	$PM_{2.5}$ (μg/m³)	2.00	632.00	39.25	48.32	35.68
	AOD (unitless)	-0.03	3.99	0.38	0.50	0.46
	WS (m/s)	0.03	18.22	3.57	3.94	2.18
	PBLH (100m)	0.71	51.45	14.69	15.68	6.85
	PS (hPa)	555.44	1038.19	997.61	968.18	69.90
	RH_PBLH (%)	7.06	97.09	48.70	49.54	16.64
	Precip_Lag1 (mm)	0.00	240.04	0.00	1.48	6.68
	Fire_spots (counts)	0.00	288.00	0.00	2.32	8.98
	ForestCover (%)	0.00	97.60	4.58	14.45	19.81
	UrbanCover (%)	0.00	100.00	19.45	24.66	21.32

[a] Abbreviations used for the meteorological variables: WS: wind speed at 10 m above ground; PBLH: planetary boundary layer height; PS: surface pressure; RH_PBLH: mean relative humidity in planetary boundary layer; Precip_Lag1: cumulative precipitation of the previous day.

Table S2 Fixed effect, model fitting and CV results of the first-stage LME model for each province for 2014 model

Province	N	Intercept [a]	Slope [a]							Fitting R²	CV R²
			AOD	WS [f]	PBLH	PS	RH_PBLH	Precip_Lag1	Fire_spots		
Anhui	13373	65.11	28.33				-57.44		0.15	0.71	0.69
Chongqing	6965	72.09	30.10			0.06		-0.13		0.80	0.76
Fujian [b]	7483	41.06	14.43	-1.52		0.09	-24.98		1.17	0.69	0.66
Gansu	5873	59.91	39.87	-1.39	-0.33	-0.07	-9.55		0.38	0.80	0.76
Guangdong [c]	7612	50.59	20.81	-1.13			-28.76		0.62	0.76	0.73
Guangxi	3227	51.84	25.49	-2.77			-19.51	-0.19	0.63	0.74	0.68
Guizhou	3490	67.78	29.12			0.12			0.09	0.81	0.73
Hebei [d]	13477	69.55	48.36	-2.41	-1.11	0.20	-73.09	-0.27	0.17	0.79	0.77
Heilongjiang	5604	53.86	46.13	-2.03					0.25	0.81	0.77
Henan	6676	73.15	30.26				-39.01		0.16	0.74	0.69
Hubei	8263	72.34	38.37				-58.79	-0.23		0.76	0.72
Hunan	6829	77.31	32.53				-64.27	-0.26		0.76	0.72
Inner Mongolia	28179	67.48	50.19	-3.17	-0.63	0.02	-53.29		0.36	0.69	0.67
Jiangsu [e]	13190	118.58	27.79	-2.22		-1.40	-44.89		0.15	0.75	0.72
Jiangxi	7108	56.69	31.44			0.37	-45.50	-0.21	0.24	0.73	0.68
Jilin	7190	56.37	43.94	-1.84			-42.23	-0.26	0.28	0.77	0.74
Liaoning	19667	58.75	36.14	-2.32			-59.05	-0.18	0.43	0.71	0.69
Ningxia	11263	60.50	40.06	-1.73		-0.05	-8.33		0.18	0.70	0.66
Qinghai	8465	66.60	36.28		-0.66		-18.73	-0.22	0.32	0.71	0.63
Shaanxi	5929	75.53	25.71			0.17			0.30	0.81	0.76
Shandong	14021	75.53	29.44	-2.39		-0.23	-48.91		0.16	0.74	0.72
Shanxi	13274	76.15	35.35			0.20	-22.82		0.14	0.73	0.70
Sichuang	12455	64.61	32.88		-0.56		-25.26	-0.20		0.71	0.68
Tibet	2976	67.43	35.61	-2.64	-0.97		-64.88	-0.31		0.81	0.73
Xinjiang	12807	60.79	43.02	-1.12	-0.39	-0.03	-18.96	-0.25		0.66	0.61
Yunnan	21163	58.04	34.61	-1.71		-0.03	-45.61	-0.15	0.20	0.67	0.64
Zhejiang	11901	62.03	31.99				-48.97		0.29	0.77	0.74

[a] Only statistically significant ($p<0.05$) intercepts and slopes are shown. [b] Including Taiwan. [c] Including Hong Kong, Macao, and Hainan. [d] Including Beijing and Tianjin. [e] Including Shanghai. [f] Abbreviations used for the meteorological variables: WS: wind speed at 10 m above ground; PBLH: planetary boundary layer height; PS: surface pressure; RH_PBLH: mean relative humidity in planetary boundary layer; Precip_Lag1: cumulative precipitation of the previous day.

Table S3 Fixed effect, model fitting and CV results of the first-stage LME model for each province for 2015 model

Province	N	Intercept [a]	Slope [a]							Fitting R²	CV R²
			AOD	WS [f]	PBLH	PS	RH_PBLH	Precip_Lag1	Fire_spots		
Anhui	13635	47.62	24.29			0.23	-45.81	-0.10	0.07	0.69	0.66
Chongqing	7024	55.05	19.47	-1.01		0.13	-8.95	-0.19	0.24	0.75	0.70
Fujian [b]	7719	34.16	10.07	-1.50	-0.27	0.04	-25.53	-0.08	0.53	0.70	0.65
Gansu	32540	59.03	32.04			0.06	-20.57	-0.27	0.05	0.62	0.60
Guangdong [c]	5853	36.64	12.24	-0.80	-0.93				0.29	0.77	0.73
Guangxi	3992	43.76	14.64	-1.92	-0.87			-0.07	0.15	0.72	0.65
Guizhou	12853	51.40	16.15	-1.49		0.09	-10.60	-0.20		0.72	0.69
Hebei [d]	9771	54.44	40.71	-2.26		0.16	-37.12			0.79	0.76
Heilongjiang	8641	41.10	28.66				-25.68		0.16	0.73	0.69
Henan	9895	61.21	29.23			0.08	-52.16	-0.21	0.08	0.69	0.65
Hubei	12826	54.70	25.27			0.14	-21.69	-0.18		0.70	0.67
Hunan	9419	55.28	22.17	-1.12		0.07	-32.24	-0.15		0.71	0.67
Inner Mongolia	31502	56.35	40.51	-1.59			-28.54	-0.10	0.21	0.62	0.60
Jiangsu [e]	12027	86.43	24.78			-0.53	-52.36		0.09	0.75	0.73
Jiangxi	17732	42.81	22.67	-2.16		0.21	-41.73	-0.07		0.66	0.63
Jilin	3755	45.83	30.60						0.19	0.79	0.71
Liaoning	9400	48.82	18.21				-17.36		0.30	0.76	0.73
Ningxia	4241	56.86	30.46							0.64	0.56
Qinghai	15971	54.07	27.86		-0.47		-9.16	-0.29		0.57	0.52
Shaanxi	5315	50.59	25.05					-0.15		0.77	0.72
Shandong	10429	75.81	31.05	-2.01		-0.33	-50.63		0.25	0.77	0.74
Shanxi	11357	62.95	29.52			0.16	-32.53	-0.19		0.74	0.71
Sichuang	8914	54.04	24.73	-1.03	-0.50	0.05	-16.26	-0.25		0.66	0.61
Tibet	7799	66.10	43.62			0.05	-60.75	-0.43		0.53	0.43
Xinjiang	7190	60.29	64.37				-34.22	-0.52		0.44	0.34
Yunnan	10510	48.94	16.79	-1.63		0.07	-11.22	-0.26	0.14	0.70	0.65
Zhejiang	10584	39.99	23.17	-1.30		0.32	-31.92	-0.07	0.00	0.78	0.75

[a] Only statistically significant ($p<0.05$) intercepts and slopes are shown. [b] Including Taiwan. [c] Including Hong Kong, Macao, and Hainan. [d] Including Beijing and Tianjin. [e] Including Shanghai. [f] Abbreviations used for the meteorological variables: WS: wind speed at 10 m above ground; PBLH: planetary boundary layer height; PS: surface pressure; RH_PBLH: mean relative humidity in planetary boundary layer; Precip_Lag1: cumulative precipitation of the previous day.

Table S4 Fixed effect, model fitting and CV results of the first-stage LME model for each province for 2016 model

Province	N	Intercept [a]	Slope [a]							Fitting R²	CV R²
			AOD	WS [f]	PBLH	PS	RH_PBLH	Precip_Lag1	Fire_spots		
Anhui	14914	44.80	24.24			0.16	-42.67	-0.10		0.76	0.73
Chongqing	9190	54.67	25.94			0.10	-39.43	-0.04	0.11	0.74	0.70
Fujian [b]	7168	31.80	10.22	-1.72		0.11	-31.00	-0.03	0.40	0.66	0.61
Gansu	9467	54.31	38.43	-1.14			-26.24	-0.18		0.74	0.70
Guangdong [c]	8286	39.28	15.12	-1.37				-0.07	0.40	0.65	0.61
Guangxi	4083	41.75	15.11	-1.64		0.05	-18.97			0.73	0.67
Guizhou	14281	48.26	20.43	-1.73		0.08	-15.63	-0.08	0.20	0.69	0.66
Hebei [d]	10642	50.53	43.07	-1.72	-0.78	0.11	-36.68	-0.13		0.79	0.77
Heilongjiang	9647	34.59	22.03			0.21	-26.11		0.09	0.70	0.65
Henan	11188	54.77	31.47			-0.03	-57.98		0.12	0.79	0.76
Hubei	15131	54.38	29.60	-0.99			-36.59	-0.10	0.12	0.73	0.71
Hunan	13082	47.55	21.75	-0.83		0.05	-18.74	-0.11	0.15	0.70	0.66
Inner Mongolia	33307	50.79	41.73	-1.79			-33.24	-0.12	0.10	0.63	0.61
Jiangsu [e]	13355	74.35	24.50			-0.42	-53.70	-0.06		0.79	0.77
Jiangxi	15457	39.13	20.02	-0.91		0.21	-23.39	-0.09	0.32	0.68	0.66
Jilin	8300	34.74	21.92		-0.51	0.22			0.08	0.74	0.69
Liaoning	19799	44.26	31.22	-2.06			-35.91		0.15	0.69	0.67
Ningxia	12035	53.18	42.44	-1.27			-31.71	-0.12		0.71	0.68
Qinghai	2993	56.11	32.53	-1.94						0.61	0.45
Shaanxi	8809	56.45	35.21			0.11	-25.20	-0.12		0.77	0.72
Shandong	11375	68.09	27.67	-2.47		-0.31			0.23	0.78	0.76
Shanxi	16385	57.44	36.74	-1.89	-0.44	0.09	-23.85	-0.09		0.75	0.73
Sichuang	4920	51.91	15.04			0.10		-0.05		0.77	0.73
Tibet	15310	59.53	40.02			0.06	-53.59	-0.07		0.52	0.44
Xinjiang	7087	53.79	59.94				-46.31	-0.37		0.59	0.45
Yunnan	11281	46.89	19.54	-1.63		0.07	-20.59	-0.07	0.16	0.67	0.63
Zhejiang	14726	31.11	19.40	-2.02		0.37	-27.66	-0.04	0.18	0.75	0.73

[a] Only statistically significant ($p<0.05$) intercepts and slopes are shown. [b] Including Taiwan. [c] Including Hong Kong, Macao, and Hainan. [d] Including Beijing and Tianjin. [e] Including Shanghai. [f] Abbreviations used for the meteorological variables: WS: wind speed at 10 m above ground; PBLH: planetary boundary layer height; PS: surface pressure; RH_PBLH: mean relative humidity in planetary boundary layer; Precip_Lag1: cumulative precipitation of the previous day.

Table S5 Fixed effect, model fitting and CV results of the first-stage LME model for each province for 2017 model

Province	N	Intercept [a]	Slope [a] AOD	WS [f]	PBLH	PS	RH_PBLH	Precip_Lag1	Fire_spots	Fitting R²	CV R²
Anhui	10643	33.34	24.43			0.43	-28.16			0.78	0.76
Chongqing	2954	40.28	12.39				14.44			0.85	0.77
Fujian [b]	8428	33.50	8.66	-1.50		0.10	-35.31	-0.12		0.65	0.61
Gansu	9362	52.93	43.23				-17.89	-0.39		0.79	0.76
Guangdong [c]	8309	37.25	15.70	-1.46				-0.07	0.36	0.71	0.67
Guangxi	4518	39.88	20.87	-2.43		0.04			0.64	0.77	0.69
Guizhou	9340	43.05	15.72	-1.53		0.05		-0.11	0.25	0.75	0.71
Hebei [d]	11179	46.71	45.70	-1.45		0.08	-46.86		0.08	0.82	0.79
Heilongjiang	6849	30.83	23.82						0.18	0.73	0.69
Henan	12266	57.19	33.39				-52.46	-0.11	0.16	0.78	0.75
Hubei	13316	52.16	29.69	-0.62				-0.13	0.22	0.76	0.73
Hunan	9302	46.88	21.65			0.09		-0.11	0.12	0.79	0.76
Inner Mongolia	35210	47.03	38.35	-1.72	-0.40		-29.59		0.24	0.65	0.63
Jiangsu [e]	12634	74.10	21.35	-1.40					0.14	0.81	0.79
Jiangxi	10413	37.41	17.66			0.32	-9.71	-0.08	0.20	0.76	0.72
Jilin	4419	30.17	22.24		-0.84				0.25	0.73	0.66
Liaoning	11202	39.08	19.20				-23.87		0.37	0.74	0.71
Ningxia	12247	53.82	47.68				-21.65	-0.46		0.78	0.75
Qinghai	16382	52.46	33.20			0.05	-20.85	-0.33		0.70	0.66
Shaanxi	7989	56.31	44.65			0.12	-30.19	-0.31		0.82	0.79
Shandong	12010	54.14	27.18	-2.29			-39.52		0.16	0.77	0.74
Shanxi	11897	60.05	38.03	-2.14	-0.47	0.03		-0.27		0.77	0.74
Sichuang	5963	48.93	11.73			0.10		-0.11		0.82	0.79
Tibet	7907	63.19	42.87			0.08	-54.34	-0.22		0.67	0.56
Xinjiang	7407	52.28	57.15				-23.09	-0.43		0.54	0.38
Yunnan	8039	45.24	19.31	-0.99		0.06	-15.24	-0.14	0.17	0.74	0.70
Zhejiang	12987	33.98	20.92	-1.48		0.26			0.24	0.77	0.75

[a] Only statistically significant ($p<0.05$) intercepts and slopes are shown. [b] Including Taiwan. [c] Including Hong Kong, Macao, and Hainan. [d] Including Beijing and Tianjin. [e] Including Shanghai. [f] Abbreviations used for the meteorological variables: WS: wind speed at 10 m above ground; PBLH: planetary boundary layer height; PS: surface pressure; RH_PBLH: mean relative humidity in planetary boundary layer; Precip_Lag1: cumulative precipitation of the previous day.
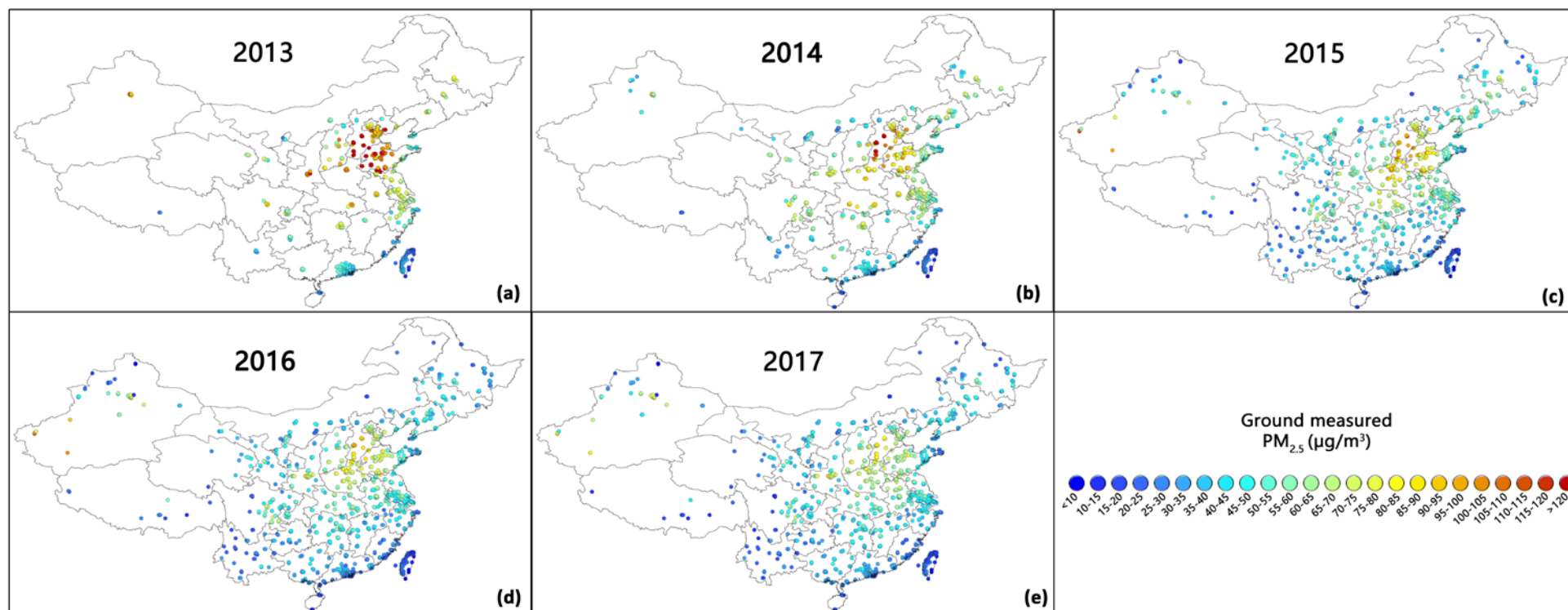
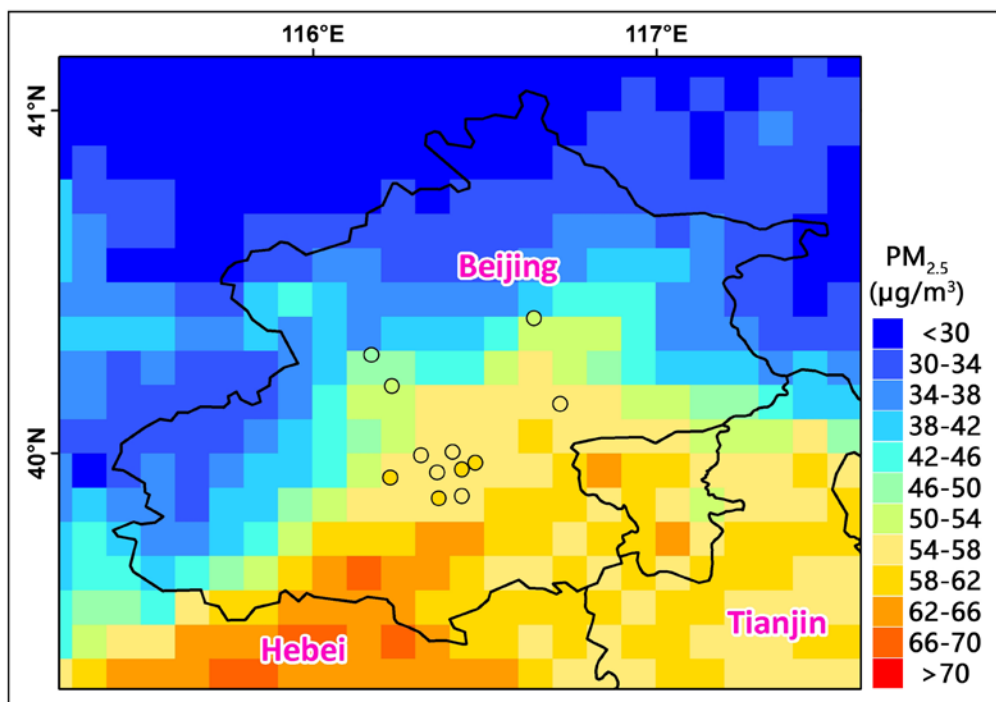**Figure S2. Spatial distributions of annual mean ground measured PM$_{2.5}$ concentrations in China from 2013 to 2017**

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Figure S3 Spatial distribution of satellite and ground PM$_{2.5}$ concentrations of 2017 in Beijing. The circles denote the ground monitoring stations.