Supporting Information for

Significant $PM_{2.5}$ mitigation in the Yangtze River Delta, China: observational constraints on surface $PM_{2.5}$ responses to anthropogenic emission controls from 2016 to 2019

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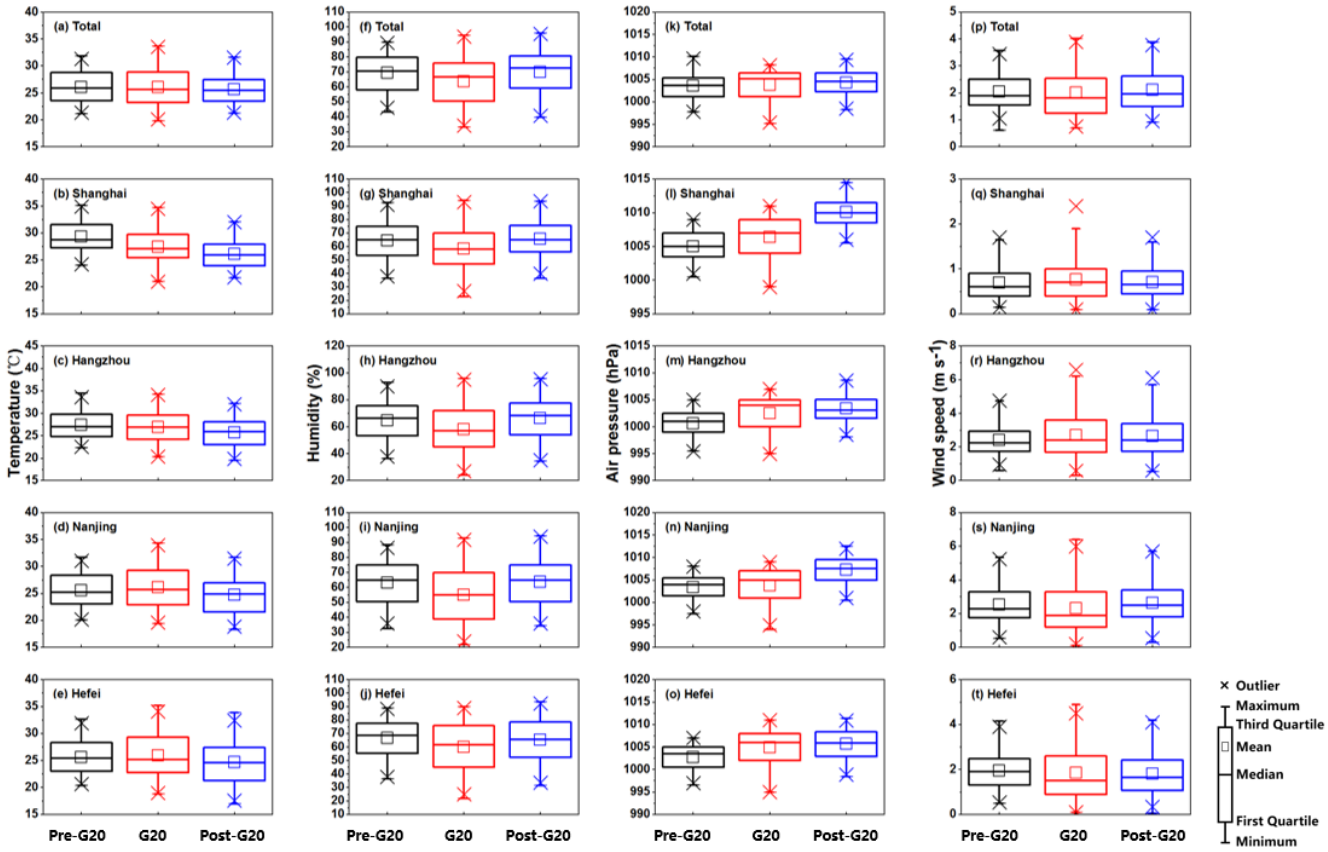

Figure S1. The reanalysed meteorological factors (i.e, temperature, relative humidity, air pressure, and wind speed) at four cities during the G20 summit and its adjacent periods (i.e., Pre- and Post- G20 periods, from August 11 to August 23, 2016 and from September 18 to September 30, 2016, respectively).

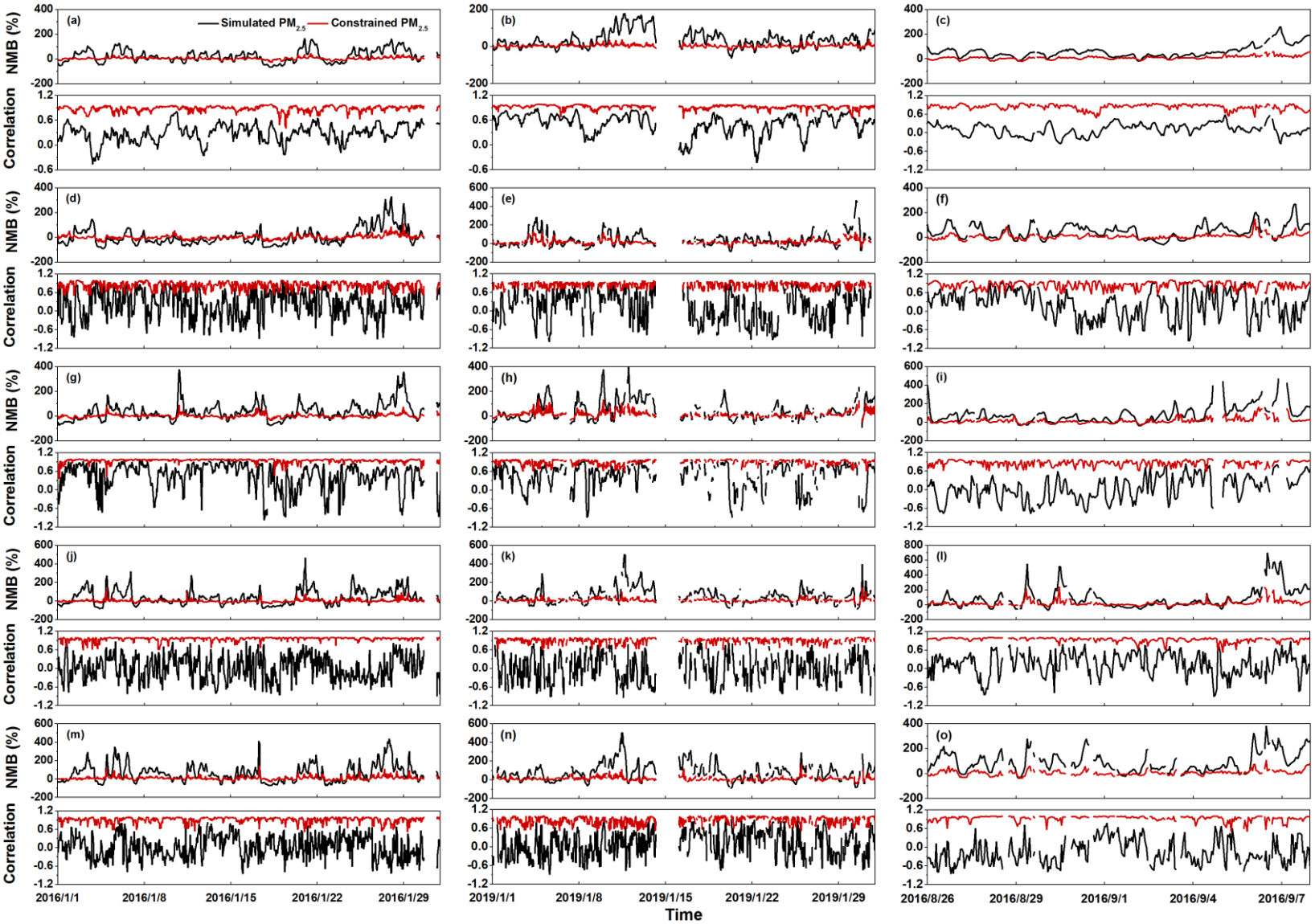

Figure S2. The NMB and R values of the simulated (black) and constrained (red) hourly $PM_{2.5}$ concentrations for January 2016 (left column), January 2019 (middle column), and the G20 summit (right column) over the whole domain (a - c) as well as in four representative cities, which are as follows: Shanghai (d - f), Hangzhou (g - i), Nanjing (j - l), and Anhui (m - o).

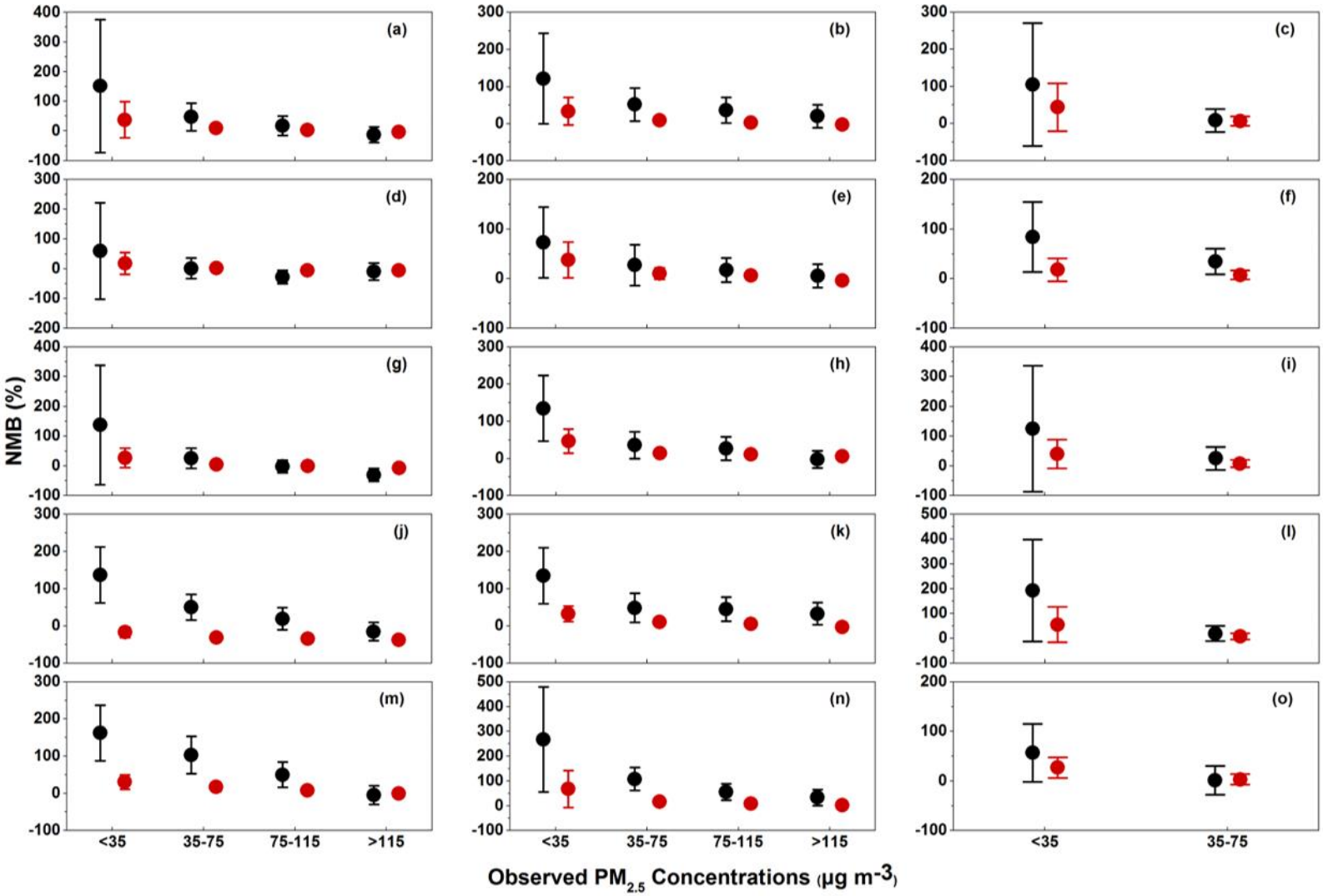

Figure S3. The mean NMB values (dots) and their standard deviations (bars) of the simulated (black) and constrained (red) hourly $PM_{2.5}$ concentrations on the basis of four intervals of the observations during January 2016 (left column), January 2019 (middle column), and the G20 summit (right column) over the whole domain (a - c) as well as in four representative cities, which are as follows: Shanghai (d - f), Hangzhou (g - i), Nanjing (j - l), and Anhui (m - o).

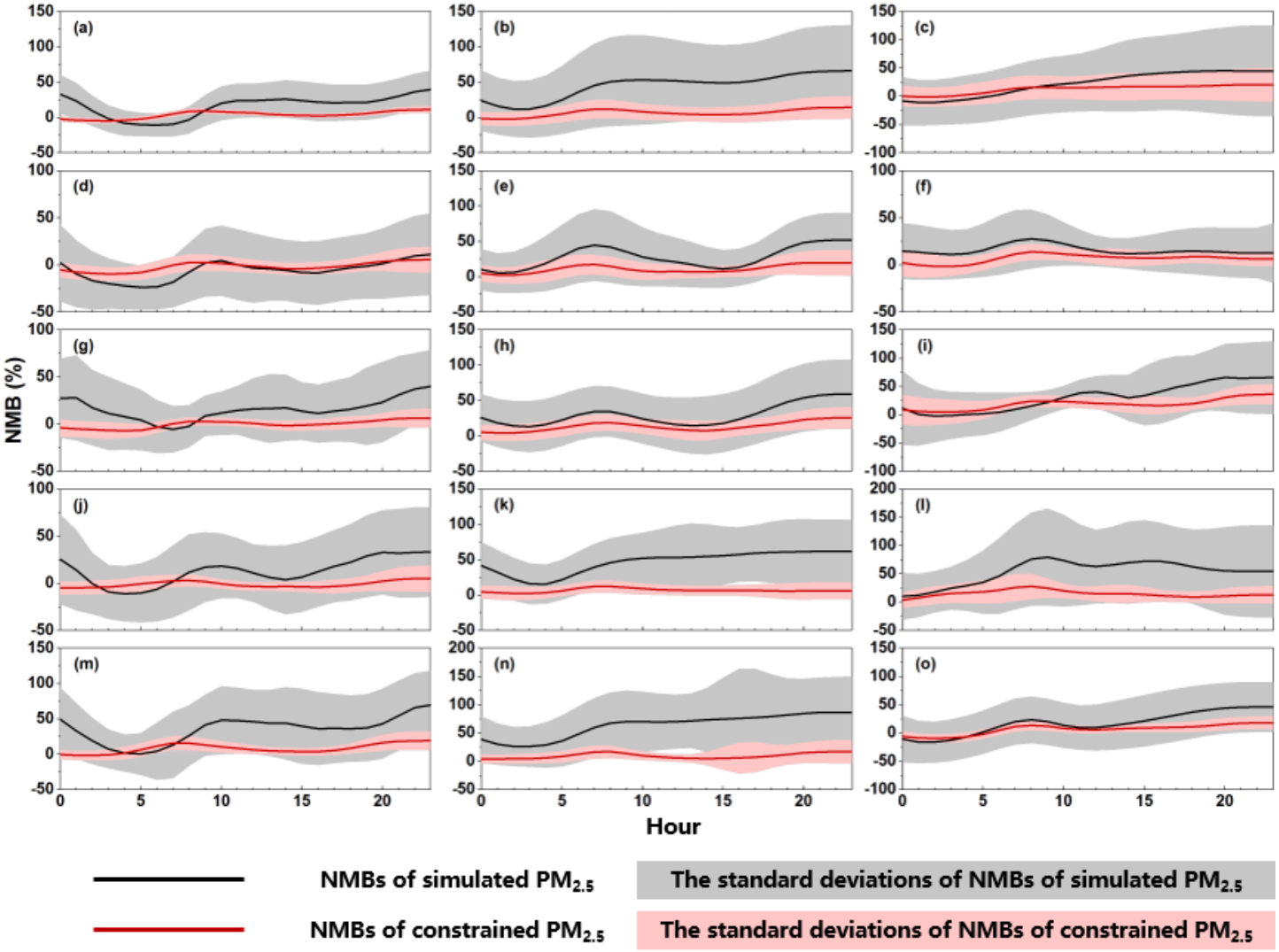

Figure S4. Time series of the mean NMB values and their standard deviations of the simulated and constrained hourly $PM_{2.5}$ concentrations for January 2016 (left column), January 2019 (middle column), and the G20 summit (right column) over the whole domain (a - c) as well as in four representative cities, which are as follows: Shanghai (d - f), Hangzhou (g - i), Nanjing (j - l), and Anhui (m - o).

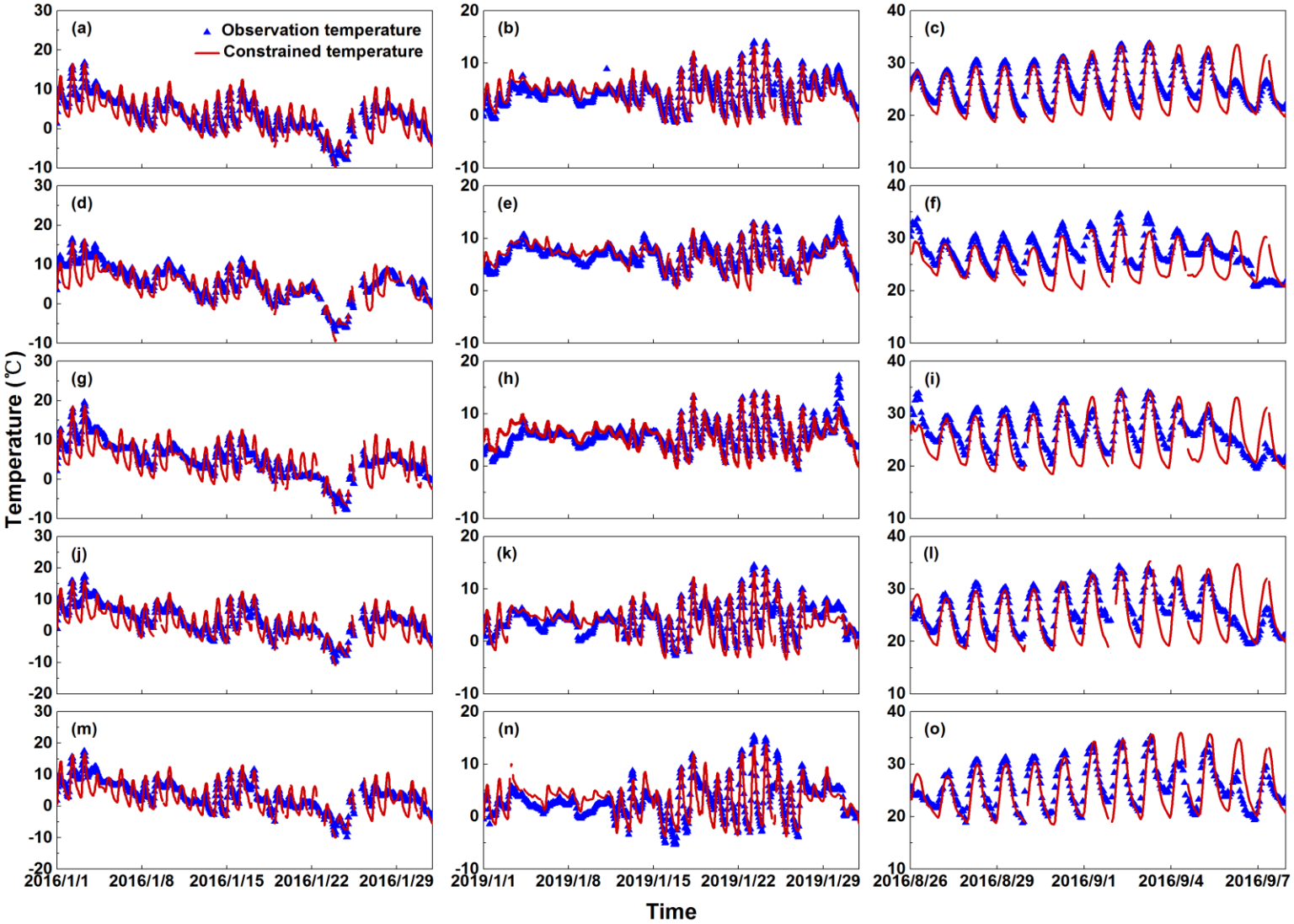

Figure S5. Time series of the hourly observed and constrained temperature for January 2016 (left column), January 2019 (middle column), and the G20 summit (right column) over the whole domain (a - c) as well as in four representative cities, which are as follows: Shanghai (d - f), Hangzhou (g - i), Nanjing (j - l), and Anhui (m - o).

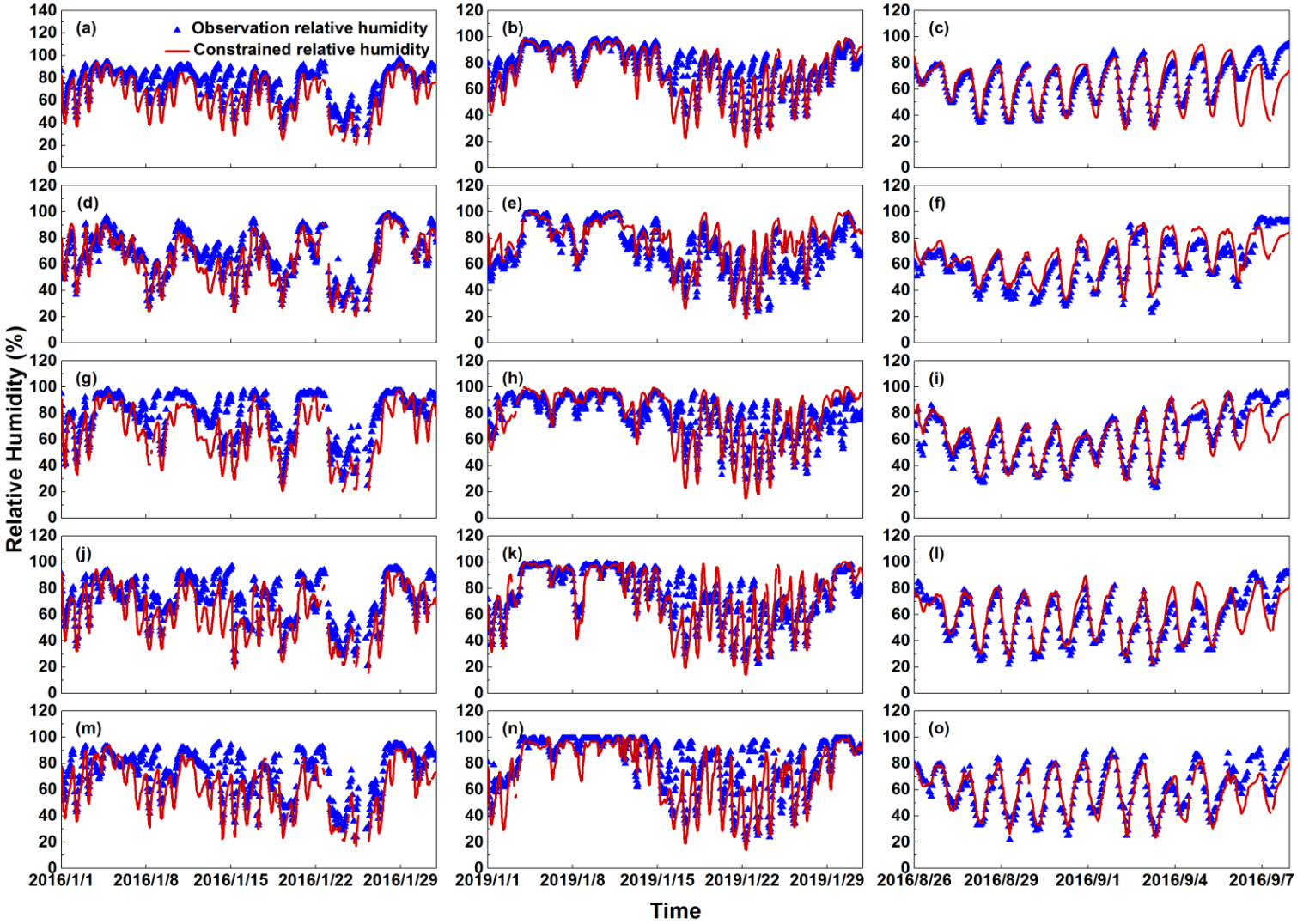

Figure S6. Time series of the comparisons between hourly observed and constrained relative humidity for January 2016 (left column), January 2019 (middle column), and the G20 summit (right column) over the whole domain (a - c) as well as in four representative cities, which are as follows: Shanghai (d - f), Hangzhou (g - i), Nanjing (j - l), and Anhui (m - o).

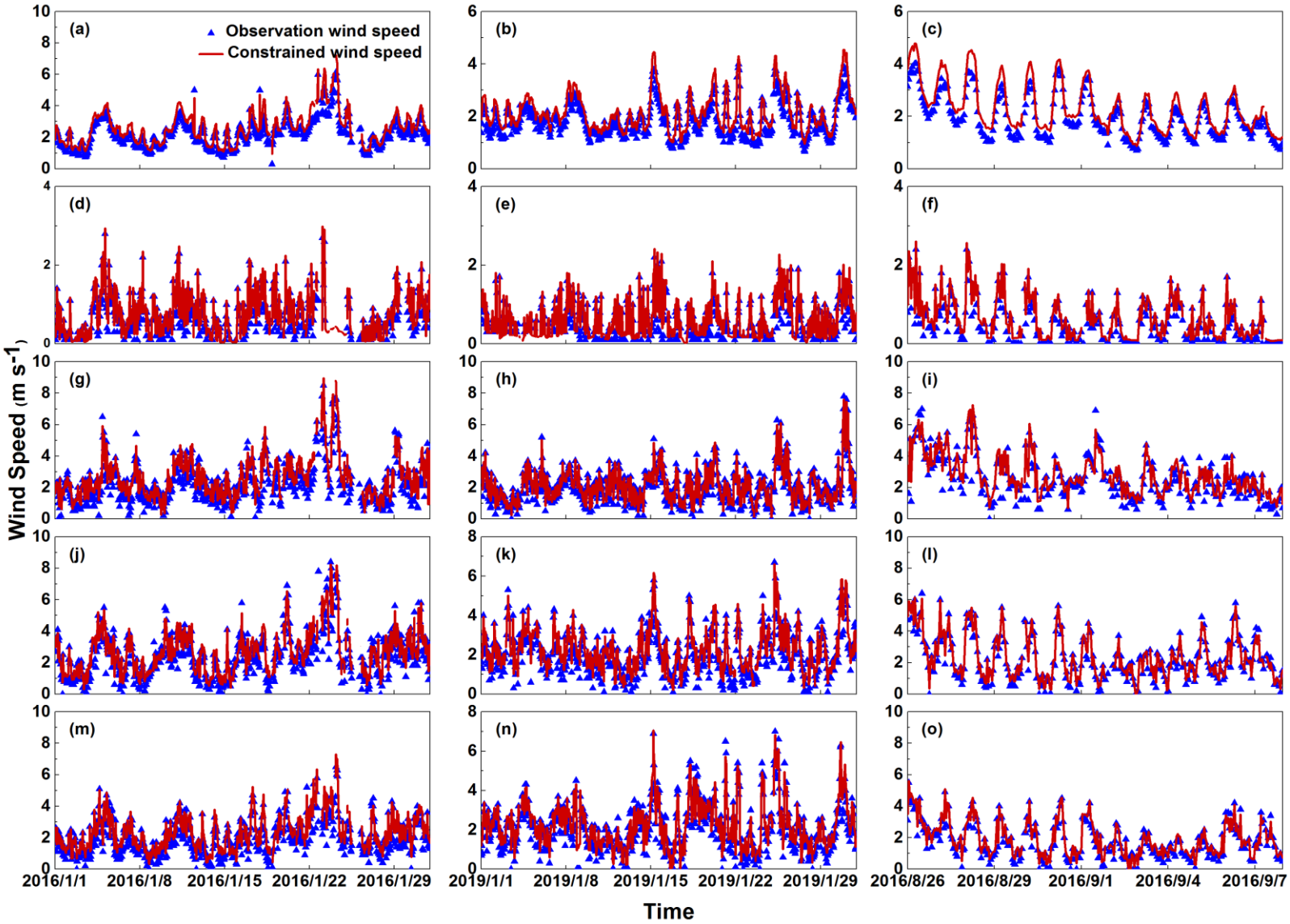

Figure S7. Time series of the comparisons between hourly observed and constrained wind speed for January 2016 (left column), January 2019 (middle column), and the G20 summit (right column) over the whole domain (a - c) as well as in four representative cities, which are as follows: Shanghai (d - f), Hangzhou (g - i), Nanjing (j - l), and Anhui (m - o).

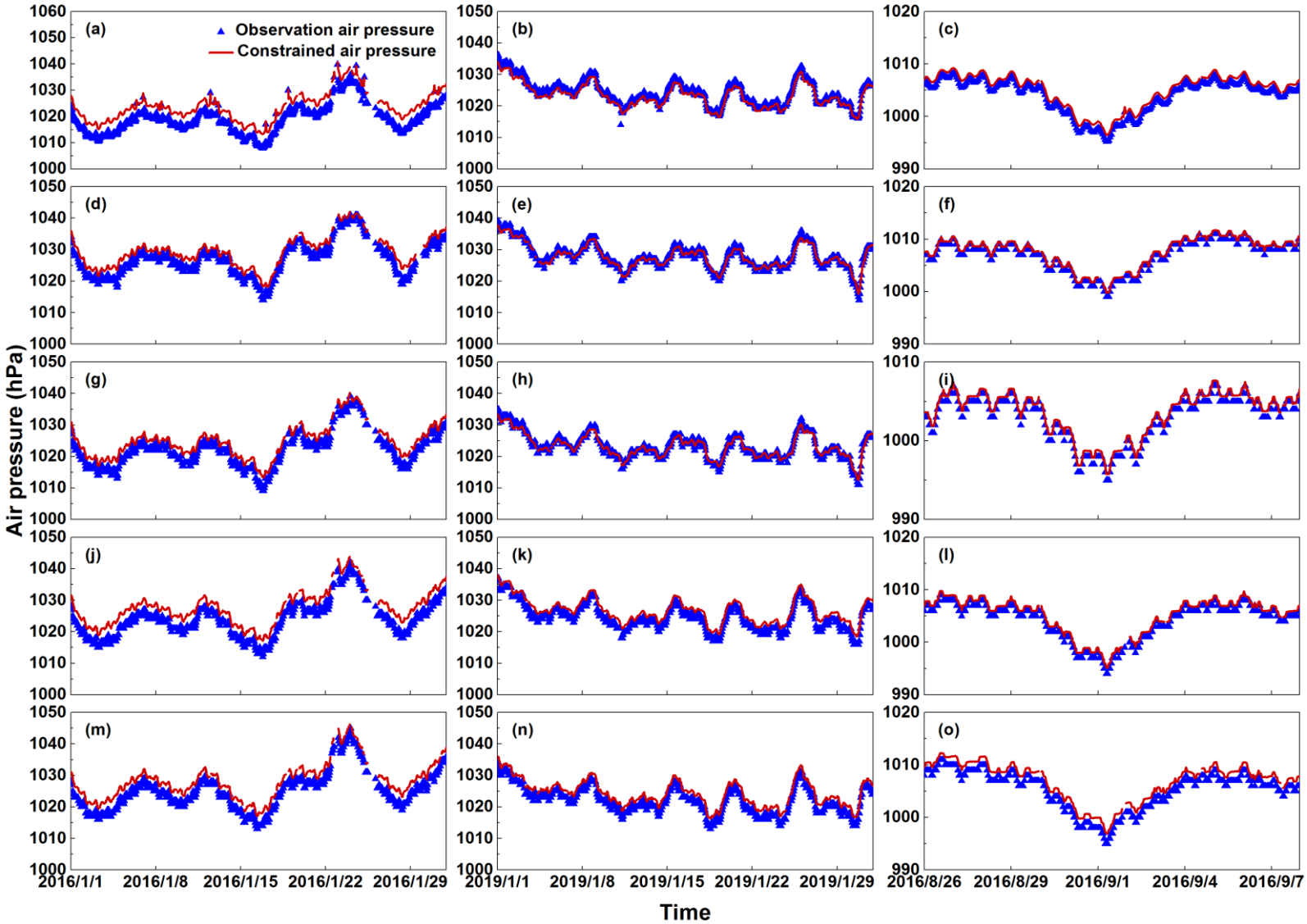

Figure S8. Time series of the comparisons between hourly observed and constrained air pressure for January 2016 (left column), January 2019 (middle column), and the G20 summit (right column) over the whole domain (a - c) as well as in four representative cities, which are as follows: Shanghai (d - f), Hangzhou (g - i), Nanjing (j - l), and Anhui (m - o).

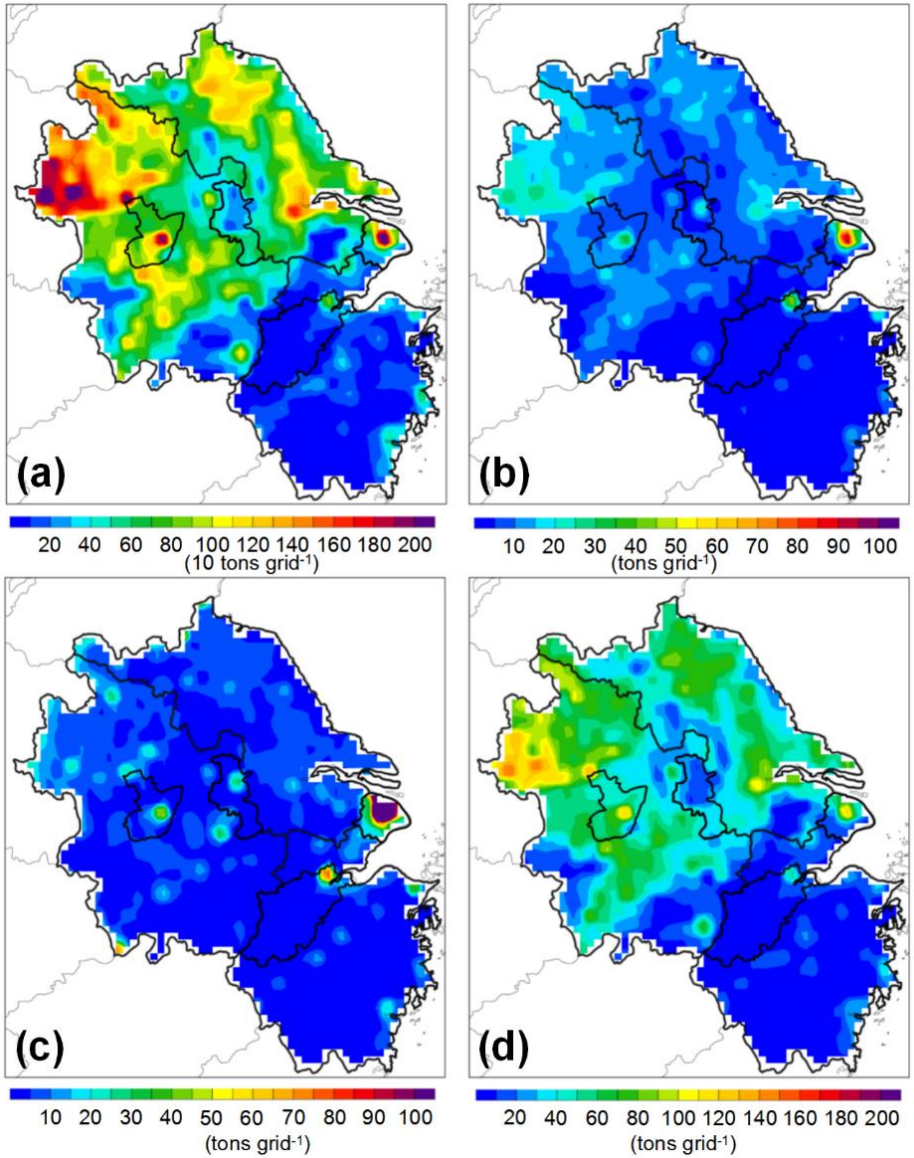

Figure S9. Spatial distributions of the monthly emissions of (a) CO, (b) NO_X, (c) SO_2, and (d) $PM_{2.5}$ in the prior anthropogenic emission inventory (MEICv1.2).

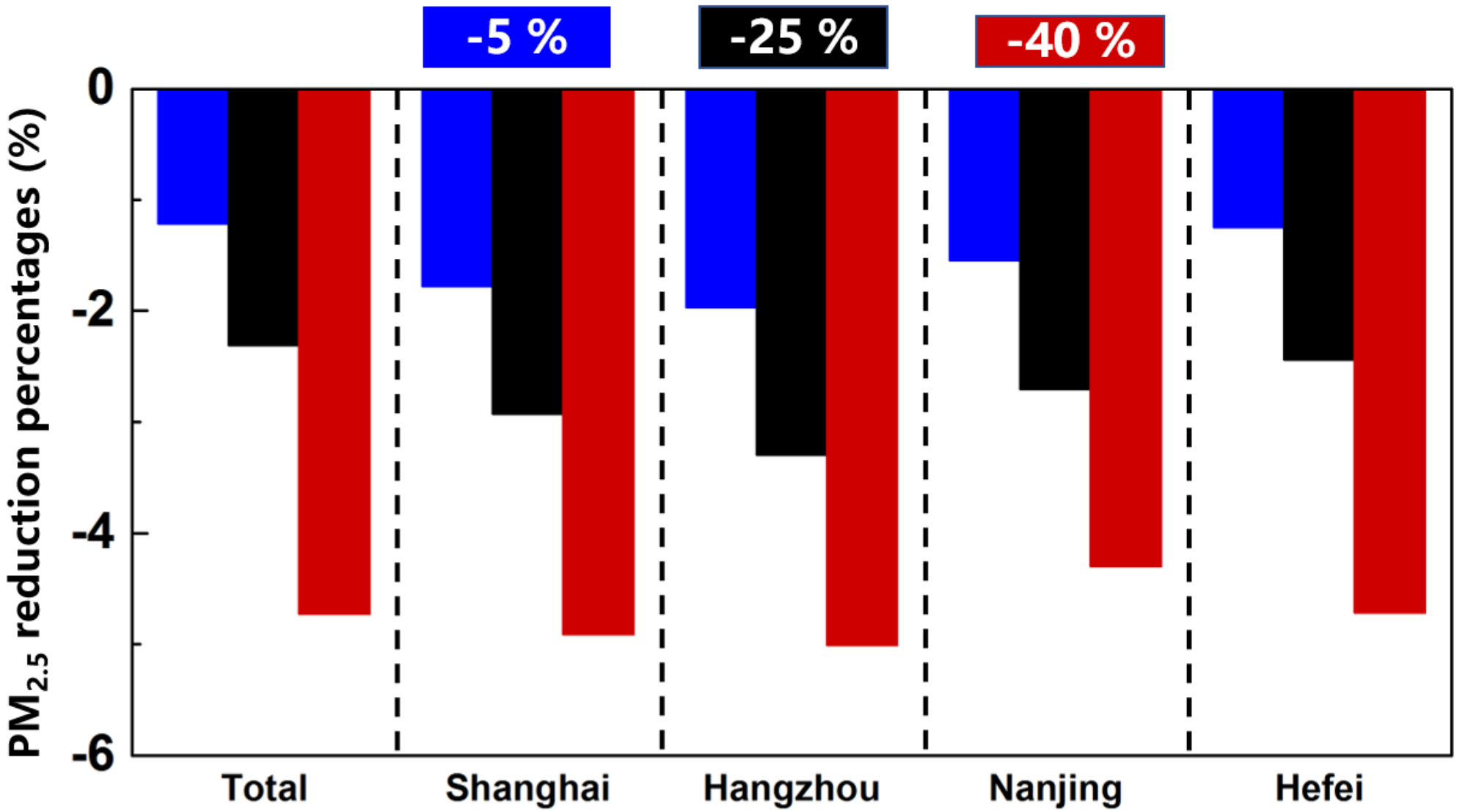

Figure S10. Meteorological impacts on $PM_{2.5}$ concentrations in three sensitivity cases over the whole domain as well as in four representative cities, which are as follows: Shanghai, Hangzhou, Nanjing, and Anhui. The three corresponding adjustment coefficients are 5 %, 25 %, and 40 %, respectively.

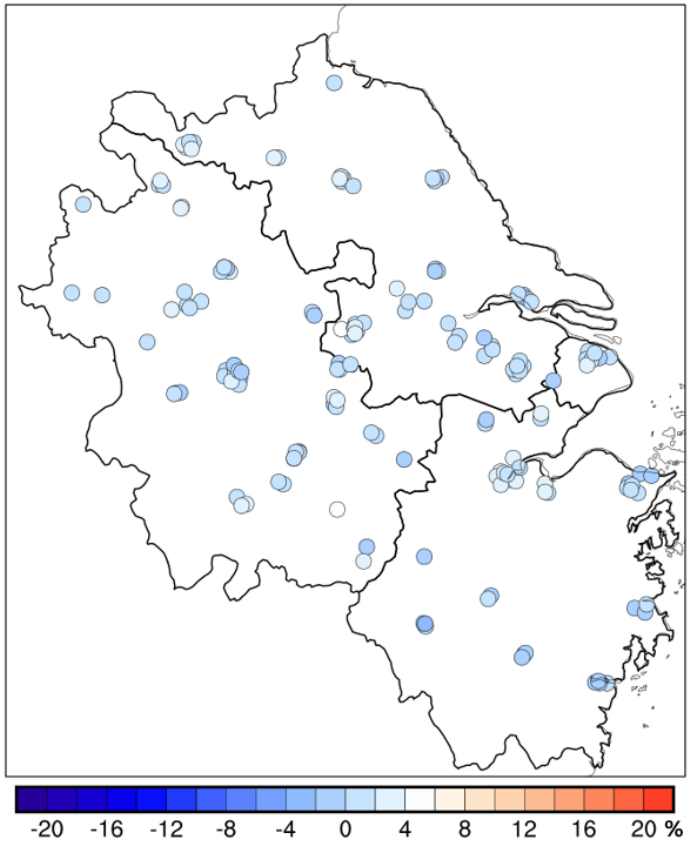

Figure S11. Standard deviations of the impacts of the inherent biases during the adjacent periods of the G20 summit (i.e., pre- and post- periods, from August 11 to August 23, 2016 and from September 18 to September 30, 2016, respectively). The dots denote the locations of ground $PM_{2.5}$ measurements.

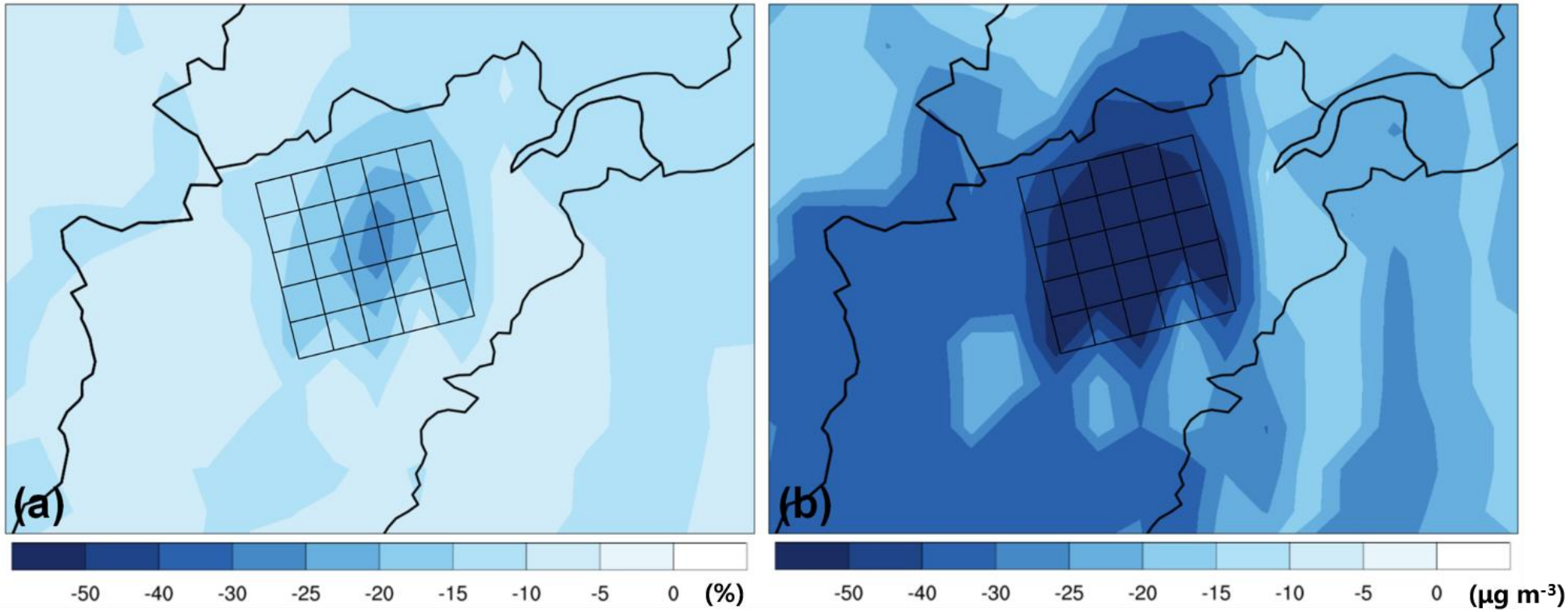

Figure S12. The enlarged part in Figure 7c. The black fishnets mark the grids covering the areas with the ultimate $PM_{2.5}$ mitigations, which are mostly located in urban Hangzhou.

Table S1. Comprehensive evaluation statistics of the constrained $PM_{2.5}$ over the whole domain as well as in four representative cities as follows: Shanghai, Hangzhou, Nanjing, and Hefei.

Episode	Area	Observed $PM_{2.5}$ ($\mu g\ m^{-3}$)	Constrained $PM_{2.5}$ ($\mu g\ m^{-3}$)		NMB (%)		RMSE ($\mu g\ m^{-3}$)		R	
			UNCONS	CONS	UNCONS	CONS	UNCONS	CONS	UNCONS	CONS
2016	Total	76.50	89.30	78.78	16.73	2.97	38.66	7.15	0.63	0.98
	Shanghai	70.40	66.30	68.94	-5.82	-2.07	46.36	11.66	0.65	0.97
	Hangzhou	75.05	86.84	74.39	15.70	-0.89	47.73	11.16	0.48	0.97
	Nanjing	79.57	89.60	78.01	12.61	-1.95	57.64	10.56	0.42	0.98
	Hefei	87.64	118.29	92.96	34.97	6.08	72.90	14.56	0.35	0.97
2019	Total	70.66	97.08	73.52	37.40	4.05	44.17	5.90	0.71	0.98
	Shanghai	48.77	62.66	54.21	28.47	11.14	34.05	10.38	0.75	0.97
	Hangzhou	59.65	78.55	67.75	31.70	13.59	43.24	14.41	0.65	0.95
	Nanjing	71.32	104.67	75.36	46.75	5.67	62.24	10.11	0.66	0.97
	Hefei	85.29	136.71	92.69	60.30	8.68	80.88	14.36	0.52	0.95
G20	Total	38.05	59.31	41.99	55.89	10.35	27.74	6.60	0.59	0.93
	Shanghai	38.91	52.73	41.56	35.49	6.80	25.77	7.43	0.60	0.95
	Hangzhou	32.05	59.39	37.25	85.29	16.20	39.60	9.92	0.33	0.79
	Nanjing	33.18	49.60	37.26	49.50	12.31	31.83	8.18	0.41	0.92
	Hefei	47.05	79.53	49.18	69.01	4.53	40.99	8.53	0.40	0.92

Table S2. Comprehensive evaluation statistics of the constrained temperature over the whole domain as well as in four representative cities as follows: Shanghai, Hangzhou, Nanjing, and Hefei.

Episode	Area	Observations (□)	Constrained temperature (□)	NMB (%)	RMSE (□)	R
2016	Total	3.67	3.09	-15.80	2.19	0.89
	Shanghai	5.67	4.55	-19.82	2.30	0.89
	Hangzhou	5.25	4.48	-14.75	2.77	0.83
	Nanjing	3.51	2.45	-30.31	2.94	0.84
	Hefei	3.80	2.75	-27.68	3.03	0.82
2019	Total	4.44	4.28	-3.53	1.31	0.90
	Shanghai	6.77	6.70	-1.06	1.30	0.85
	Hangzhou	5.93	5.87	-1.12	1.59	0.82
	Nanjing	4.18	3.58	-14.42	1.86	0.84
	Hefei	3.07	3.16	2.74	2.05	0.82
G20	Total	25.84	24.91	-3.61	2.19	0.90
	Shanghai	27.10	25.32	-6.55	2.97	0.72
	Hangzhou	26.48	25.02	-5.51	3.32	0.73
	Nanjing	25.86	24.81	-4.07	2.57	0.76
	Hefei	25.87	25.44	-1.70	2.96	0.80

Table S3. Comprehensive evaluation statistics of the constrained relative humidity over the whole domain as well as in four representative cities as follows: Shanghai, Hangzhou, Nanjing, and Hefei.

Episode	Area	Observations (%)	Constrained RH (%)	NMB (%)	RMSE (%)	R
2016	Total	75.41	63.95	-15.21	13.25	0.93
	Shanghai	67.89	64.13	-5.53	7.92	0.93
	Hangzhou	78.85	66.72	-15.39	14.44	0.92
	Nanjing	71.58	62.02	-13.31	13.33	0.87
	Hefei	73.47	61.74	-15.96	15.01	0.87
2019	Total	77.62	72.87	-6.12	10.41	0.89
	Shanghai	71.72	77.27	7.74	11.45	0.84
	Hangzhou	77.65	77.79	0.18	12.47	0.81
	Nanjing	74.75	73.54	-1.63	12.22	0.85
	Hefei	80.91	72.82	-10.00	15.15	0.83
G20	Total	65.34	63.97	-2.09	11.21	0.76
	Shanghai	60.67	66.07	8.91	9.83	0.88
	Hangzhou	62.27	62.63	0.57	8.83	0.88
	Nanjing	57.25	60.09	4.95	7.06	0.87
	Hefei	61.13	59.08	-3.36	8.01	0.89

Table S4. Comprehensive evaluation statistics of the constrained wind speed over the whole domain as well as in four representative cities as follows: Shanghai, Hangzhou, Nanjing, and Hefei.

Episode	Area	Observations ($m\ s^{-1}$)	Constrained Wind speed ($m\ s^{-1}$)	NMB (%)	RMSE ($m\ s^{-1}$)	R
2016	Total	2.22	2.62	17.91	0.47	0.98
	Shanghai	0.70	0.73	4.01	0.17	0.99
	Hangzhou	2.27	2.61	15.34	0.55	0.95
	Nanjing	2.40	2.70	12.72	0.46	0.97
	Hefei	1.99	2.33	17.42	0.49	0.96
2019	Total	1.86	2.16	15.85	0.33	0.98
	Shanghai	0.62	0.62	0.25	0.23	0.97
	Hangzhou	1.99	2.10	5.16	0.17	0.99
	Nanjing	2.05	2.30	12.08	0.35	0.97
	Hefei	2.13	2.31	8.35	0.32	0.98
G20	Total	1.96	2.32	18.33	0.41	0.99
	Shanghai	0.51	0.64	26.10	0.14	0.99
	Hangzhou	2.61	2.83	8.64	0.46	0.96
	Nanjing	2.25	2.36	4.73	91.12	0.99
	Hefei	1.82	1.93	6.12	0.23	0.99

Table S5. Comprehensive evaluation statistics of the constrained air pressure over the whole domain as well as in four representative cities as follows: Shanghai, Hangzhou, Nanjing, and Hefei.

Episode	Area	Observations (hPa)	Constrained air pressure (hPa)	NMB (%)	RMSE (hPa)	R
2016	Total	1019.08	1023.50	0.43	4.48	0.99
	Shanghai	1026.53	1029.26	0.27	2.84	0.99
	Hangzhou	1021.98	1024.79	0.28	2.90	0.99
	Nanjing	1023.71	1027.61	0.38	3.94	0.99
	Hefei	1024.72	1028.18	0.34	3.50	0.99
2019	Total	1024.25	1023.27	-0.10	1.17	0.99
	Shanghai	1027.72	1027.73	0.00	0.81	0.98
	Hangzhou	1023.15	1023.21	0.01	0.84	0.99
	Nanjing	1024.63	1026.72	0.20	2.20	0.99
	Hefei	1022.00	1024.36	0.23	2.39	0.99
G20	Total	1003.93	1005.01	0.11	1.09	0.99
	Shanghai	1006.99	1007.54	0.06	0.64	0.99
	Hangzhou	1002.85	1003.52	0.07	0.68	0.99
	Nanjing	1004.13	1005.05	0.09	6.70	0.99
	Hefei	1005.18	1006.84	0.16	1.67	0.99

Table S6. Different effects between the long-term emission controls from 2016 to 2019 and the emergency emission controls during the G20 summit on $PM_{2.5}$.

Effect	Region	Net impacts (μg/m3 / %)	Meteorological impacts (μg/m3 / %)	Anthropogenic impacts (μg/m3 / %)
Long-term emission controls	YRD	-2.13/-3.15	11.51/16.21	-13.64/-19.36
	Shanghai	-13.26/-21.22	5.41/17.55	-18.67/-38.77
	Hangzhou	-12.51/-17.18	5.88/19.57	-18.39/-36.75
	Nanjing	-6.32/-8.41	16.51/24.52	-22.83/-32.93
	Hefei	-2.31/-2.71	18.31/20.55	-20.62/-23.26
Emergency emission controls	YRD	-17.23/-41.45	4.83/2.57	-22.06/-44.02
	Shanghai	-11.33/-24.20	9.72/20.95	-20.95/-45.16
	Hangzhou	-21.31/-42.40	2.88/5.76	-24.21/-48.17
	Nanjing	-15.54/-31.51	5.27/10.70	-20.82/-42.21
	Hefei	-12.53/-27.05	5.22/11.27	-17.75/-38.33