Temporally-resolved sectoral and regional contributions to air pollution in Beijing: Informing short-term emission controls (Supplementary Material)

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Table S1. Summary of the contributions to $PM_{2.5}$ in Beijing from each one-day pulse in emissions from Beijing, Near-neighbourhood and Far-neighbourhood sources showing the magnitude and timing of the peak contribution and the integrated contribution from each source region

Start date	Peak contribution ($\mu g\, m^{-3}$)			Time to reach peak (h)			Length of contribution (h)			Integrated contribution ($\mu g\, m^{-3}$ h)		
	Beijing	Near	Far	Beijing	Near	Far	Beijing	Near	Far	Beijing	Near	Far
Polluted period												
18 Oct	33.1	33.7	15.0	16	30	46	28	44	61	393	386	244
19 Oct	29.9	21.6	1.9	14	24	31	35	36	44	503	320	30
20 Oct	13.0	5.8	3.8	12	21	103	23	116	117	171	108	203
21 Oct	18.6	11.5	6.6	16	33	79	33	101	93	225	560	153
22 Oct	26.5	27.4	15.8	15	39	58	34	93	95	367	913	398
23 Oct	28.8	43.1	6.0	15	36	61	40	71	72	533	795	87
24 Oct	31.0	22.9	5.5	14	37	38	48	48	49	663	226	73
25 Oct	43.5	0.6	1.3	14	103	19	24	66	49	496	1	8
26 Oct	8.3	9.2	3.1	13	34	105	25	45	50	95	69	57
27 Oct	20.9	10.3	8.2	17	33	82	30	91	101	270	462	307
Clean period												
02 Nov	19.0	0.2	2.6	14	33	37	25	30	74	138	1	91
03 Nov	21.8	4.7	8.5	13	28	40	35	49	55	296	92	137
04 Nov	29.3	7.8	4.4	16	21	34	26	28	34	379	70	28
05 Nov	20.6	0.3	2.8	12	91	87	23	119	99	146	3	46
06 Nov	19.2	8.8	4.0	13	58	38	26	74	77	147	236	153
07 Nov	33.2	3.2	1.8	17	17	44	33	28	105	366	49	52
08 Nov	27.4	2.8	4.4	13	20	37	25	24	99	358	15	124
09 Nov	28.0	2.6	5.6	13	28	35	29	79	69	298	13	136
10 Nov	36.2	3.1	3.1	14	14	20	24	69	31	350	12	30
11 Nov	11.3	0.7	1.2	12	30	15	22	119	46	113	2	12

For each start day, five-day simulations were performed with emissions from each of the three source regions reduced in turn on the first day of the run only, as shown in S1. Contributions were calculated by subtracting hourly $PM_{2.5}$ concentrations from the baseline run. A 24-h running average was applied to the hourly absolute contributions to calculate the timing of the peak contribution.

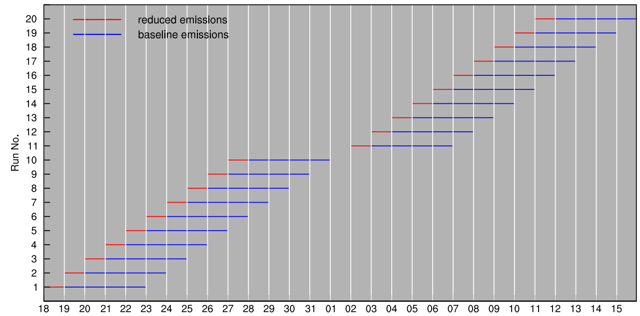

Figure S1. Schematic showing start and end dates of each one-day emission reduction simulation between 12 October and 15 November. These runs were performed for each of the three source regions in turn.

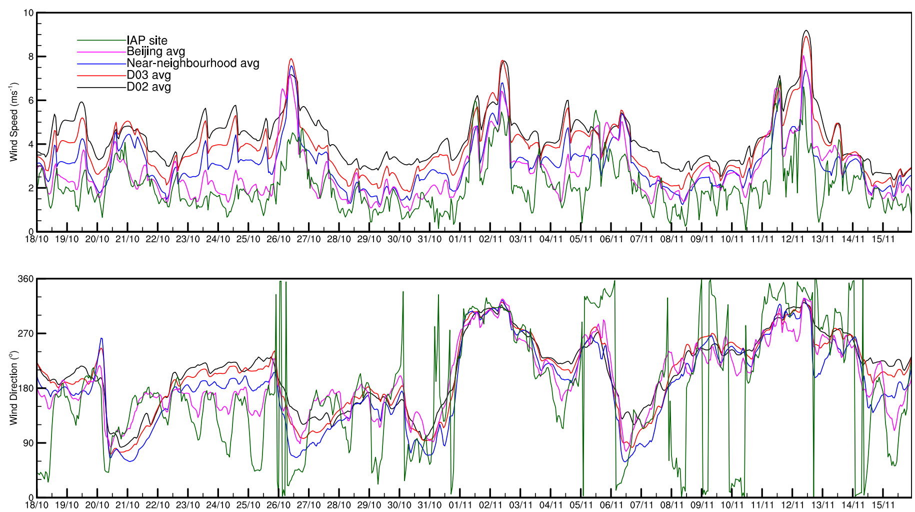

Figure S2. Time series of simulated hourly wind speed and direction sampled from the Institute of Atmospheric Physics (IAP) grid point, and spatially averaged values over Beijing, Near-Neighbourhood region, model domain 2 and 3. Model domain 2 (D02) is the same as shown in Figure 2 and domain 3 (D03) is the same as shown in Figure 8.

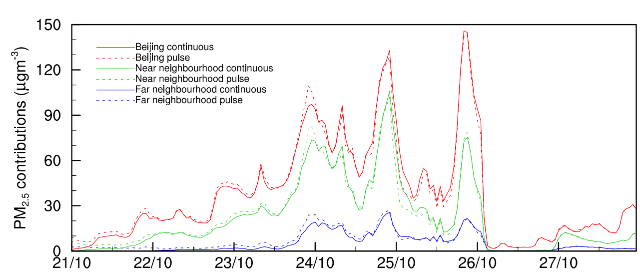

Figure S3. Comparison of cumulative contributions to $\mathrm{PM}_{2.5}$ in Beijing from continuous emission controls (solid lines) with those from successive one-day pulses in emissions (dashed lines) from local, near-neighbourhood and far-neighbourhood source regions.

Table S2. Scaling factors applied to the 12 emission sources for each of the 60 runs used to generate the emulators.

Run No.	Beijing–Industry	Beijing–Power	Beijing–Transport	Beijing–Residential	NN–Industry	NN–Power	NN–Transport	NN–Residential	FN–Industry	FN–Power	FN–Transport	FN–Residential
1	0.730	1.055	0.620	0.509	0.907	0.280	0.974	0.150	0.505	0.992	0.128	0.602
2	0.949	0.923	1.020	0.255	0.420	0.040	1.149	1.028	0.574	0.160	1.061	0.055
3	0.101	0.322	0.669	0.225	0.161	1.051	0.684	0.047	0.095	0.204	0.434	0.686
4	0.594	0.164	0.206	0.061	1.062	0.199	0.829	0.077	0.365	0.690	0.512	0.771
5	0.042	0.945	1.185	0.993	0.414	0.141	0.887	0.400	1.094	1.177	0.539	1.084
6	0.247	1.013	0.176	1.139	1.094	1.175	0.451	0.990	0.943	0.387	0.191	0.810
7	0.322	0.416	0.688	0.498	1.135	0.309	0.983	0.352	0.875	0.959	0.173	1.189
8	0.009	0.789	0.709	0.527	0.920	0.229	0.049	0.637	0.841	1.139	0.768	1.136
9	0.658	0.457	0.798	0.378	0.460	0.734	0.790	0.948	1.159	0.522	0.660	1.160
10	0.274	0.536	0.094	0.029	0.094	0.572	0.847	0.681	0.748	0.711	0.994	0.369
11	0.536	0.668	0.727	0.900	0.034	0.758	1.185	1.058	0.661	0.021	0.267	0.542
12	0.845	1.137	0.255	0.479	0.265	0.540	0.352	0.473	0.980	0.403	0.970	0.333
13	0.411	0.372	1.076	0.676	0.869	0.670	0.674	0.857	0.265	1.069	0.340	0.745
14	0.786	0.593	0.144	0.558	1.104	0.386	0.136	0.715	1.182	0.816	0.086	1.180
15	0.511	0.516	0.517	0.682	0.392	0.866	0.616	0.793	0.017	0.622	0.898	0.073
16	1.043	0.061	0.559	1.004	0.970	0.209	0.491	0.617	0.547	0.483	0.077	0.507
17	0.027	0.118	0.871	0.581	0.055	1.025	0.750	1.151	0.438	0.932	0.231	0.171
18	0.442	0.850	0.185	0.601	0.281	0.544	1.100	0.219	1.020	0.276	1.195	0.262
19	0.567	0.764	0.607	0.818	0.073	0.422	0.027	0.442	0.308	0.659	1.111	0.673
20	1.193	0.882	0.314	0.433	1.162	0.376	0.420	0.025	0.905	0.433	1.059	1.049
21	0.695	0.997	1.165	0.771	0.138	1.018	1.047	0.739	0.713	0.789	1.096	0.450
22	1.032	0.714	0.108	0.154	0.204	1.193	0.236	0.162	1.120	0.352	0.709	0.910
23	0.097	0.193	0.849	0.972	0.530	0.408	0.012	0.820	0.400	1.198	1.022	0.526
24	0.176	0.907	0.943	0.107	0.672	0.653	0.410	0.262	0.188	0.745	0.026	0.213
25	0.619	1.101	0.373	0.338	0.319	0.681	0.264	0.898	0.036	0.587	0.149	0.186
26	0.500	0.825	0.432	0.736	0.324	0.764	0.517	1.139	0.823	0.905	1.017	0.561
27	0.977	0.488	0.776	1.093	1.017	0.883	1.134	0.974	0.412	0.139	0.638	0.233
28	0.806	0.300	0.990	1.080	1.052	0.906	1.018	0.577	1.122	0.224	0.616	0.825
29	1.174	0.093	0.835	0.178	0.799	0.090	0.090	0.300	0.072	0.002	0.295	0.582
30	0.310	1.161	0.584	0.705	1.035	0.446	0.730	1.095	0.352	0.826	0.939	0.418
31	0.399	1.195	1.151	0.564	0.888	0.472	0.205	1.186	0.465	0.193	0.445	0.248
32	0.998	0.462	0.534	0.850	0.563	0.964	0.873	1.102	0.137	0.861	0.251	0.659
33	0.422	0.750	0.815	1.169	0.621	0.923	1.175	0.091	0.584	0.459	0.866	1.010
34	0.376	0.730	0.914	0.647	0.518	1.141	0.717	0.380	0.680	0.380	0.205	0.111
35	1.004	0.387	0.754	0.888	0.836	1.093	0.158	0.656	0.460	0.555	1.138	0.629
36	0.868	0.046	0.461	1.052	0.843	0.835	0.108	0.194	0.888	0.083	0.686	0.032
37	1.103	0.602	0.064	1.021	0.643	0.595	0.560	0.400	0.162	0.109	0.757	0.982
38	0.135	0.012	0.966	0.310	0.990	0.811	1.062	0.921	0.339	0.257	0.003	0.010
39	1.070	0.639	0.269	1.107	0.682	1.061	0.761	0.498	0.769	1.112	0.473	0.347
40	0.839	0.243	0.481	0.865	0.224	0.984	1.106	0.915	0.732	0.053	0.948	0.462
41	1.149	0.153	0.231	0.285	0.114	1.132	0.536	0.813	0.118	1.036	0.919	1.036
42	0.471	0.878	0.574	1.183	0.734	0.629	0.364	0.424	0.793	0.890	1.175	0.392
43	0.181	0.660	1.125	0.082	0.243	0.007	0.912	0.013	0.220	0.564	0.860	1.115
44	0.287	1.159	0.649	0.260	1.155	0.792	0.311	0.244	0.298	0.294	0.586	0.785
45	0.710	0.134	0.413	0.942	0.149	0.077	0.937	0.559	0.818	0.853	0.802	0.140
46	0.741	0.542	1.091	0.448	0.610	0.340	0.199	0.331	0.057	0.612	1.144	0.292
47	0.671	0.340	1.106	0.793	0.808	1.103	0.079	0.315	0.156	1.047	0.568	0.895
48	0.776	1.072	0.932	0.635	0.186	0.117	0.654	0.865	0.980	1.006	0.786	0.428
49	0.552	0.204	0.007	0.921	0.717	0.266	0.477	1.066	1.179	0.317	0.542	0.974
50	0.905	0.817	0.322	0.833	0.376	0.351	0.396	0.511	0.625	0.331	0.051	1.061
51	0.077	0.425	0.046	0.211	0.585	0.958	0.168	0.763	0.922	0.737	0.491	0.848
52	0.893	0.233	0.022	0.418	0.751	0.509	0.952	1.017	0.610	0.469	0.312	0.952
53	0.156	0.034	1.060	0.181	0.341	0.480	0.816	0.596	1.060	0.960	0.827	0.726
54	1.086	0.564	0.400	0.047	0.007	0.242	0.291	0.536	0.485	1.090	0.113	0.152
55	0.239	0.264	0.356	0.747	1.190	0.851	0.324	0.676	0.534	0.080	0.647	0.300
56	0.213	1.040	0.889	0.398	0.480	0.704	0.584	0.116	1.034	0.771	0.405	0.497
57	0.342	0.973	0.458	0.136	0.774	0.169	0.626	1.169	0.210	0.661	0.329	0.936
58	0.637	0.315	1.017	0.358	0.459	0.135	0.241	0.757	0.645	1.159	0.389	0.719
59	0.934	0.698	0.137	1.151	0.543	0.027	0.540	0.133	0.252	0.152	0.726	0.097
60	1.123	1.082	0.280	0.004	0.945	0.601	1.031	0.236	1.042	0.510	0.380	0.865

The near-neighbourhood region is labelled NN and the far-neighbourhood region is labelled FN.

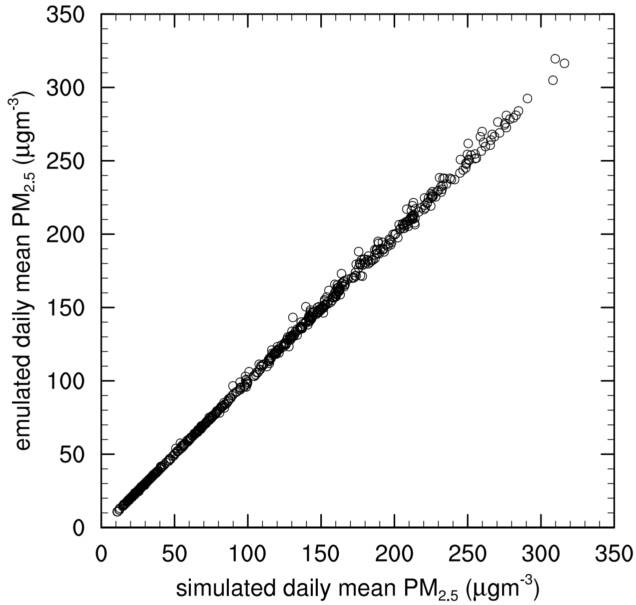

Figure S4. Comparison of simulated versus emulated daily mean $\mathrm{PM}_{2.5}$ in Beijing for emulator validation. For each day of the period 60 different emulators were built leaving out one set of model output and validating against this set; correlation co-efficient r = 0.999.

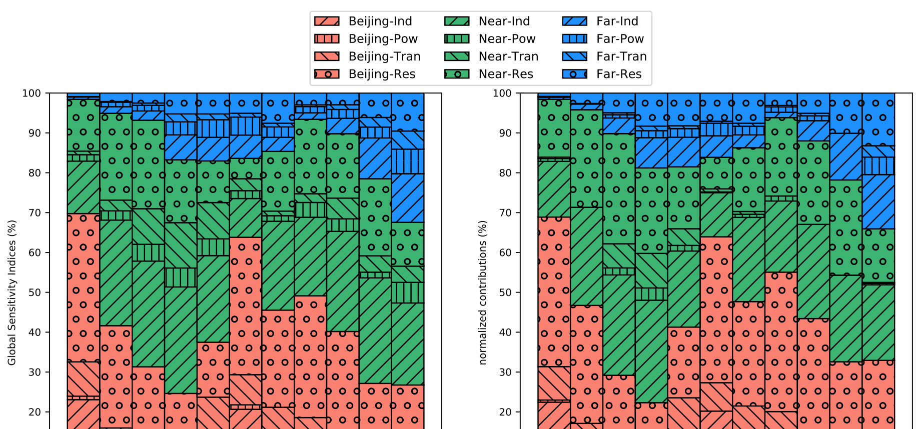

Figure S5. Comparison of contributions to daily mean $\mathrm{PM}_{2.5}$ concentrations from the 12 emission sources derived from global sensitivity analysis of emulated output using the eFAST algorithm (left) and normalized contributions obtained from one-at-a-time sensitivity runs with WRF-Chem (right).

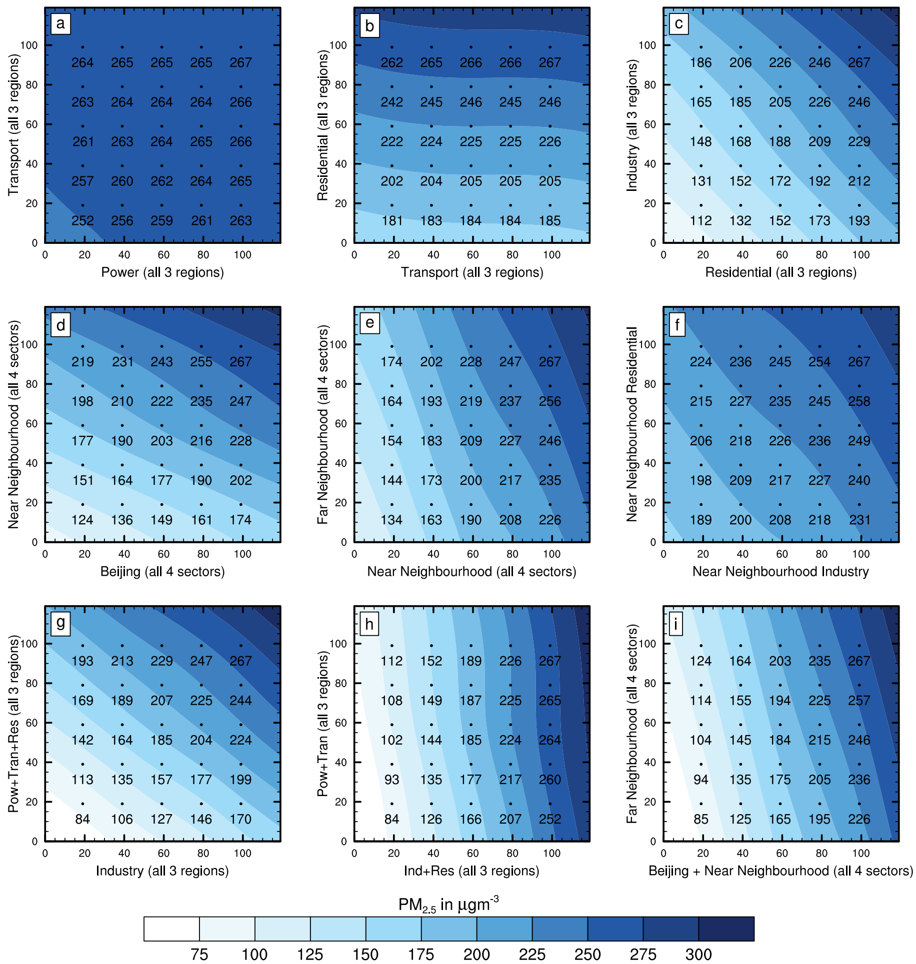

Figure S6. Response of daily average $\mathrm{PM}_{2.5}$ concentrations in Beijing to changes in sectoral and regional emissions. Axes show the scaling applied to the relevant source (in %) starting on 21 October; contours show the corresponding daily mean $\mathrm{PM}_{2.5}$ in Beijing on 30 October (concentrations at 20% intervals are labelled).