Supplementary Information for "Health burdens related to emission sources and cross-province air pollution in China"

Weiyang Hu[1], Bo Zheng[3], Daven K. Henze[4], Ni Lu[5], Xiaolin Wang[6], Lin Zhang[5], Tzung-May Fu[7], Yu Zhao[1,2*]

[1]State Key Laboratory of Pollution Control and Resource Reuse and School of the Environment, Nanjing University, 163 Xianlin Rd., Nanjing, Jiangsu 210023, China

[2]Jiangsu Collaborative Innovation Center of Atmospheric Environment and Equipment Technology (CICAEET), Nanjing University of Information Science and Technology, Jiangsu 210044, China

[3]Institute of Environment and Ecology, Tsinghua Shenzhen International Graduate School, Tsinghua University, Shenzhen, Guangdong 518055, China

[4]Department of Mechanical Engineering, University of Colorado Boulder, Boulder, Colorado 80309, United States

[5]Laboratory for Climate and Ocean-Atmosphere Sciences, Department of Atmospheric and Oceanic Sciences, School of Physics, Peking University, Beijing 100871, China

[6]John A. Paulson School of Engineering and Applied Sciences, Harvard University, Cambridge, Massachusetts 02138, United States

[7]State Environmental Protection Key Laboratory of Integrated Surface Water-Groundwater Pollution Control, Guangdong Provincial Key Laboratory of Soil and Groundwater Pollution Control, School of Environmental Science and Engineering, Southern University of Science and Technology, Shenzhen, Guangdong 518055, China

*Corresponding author: Yu Zhao Phone 86-25-89680650; email: yuzhao@nju.edu.cn

Table of Contents

This PDF file includes:

FIGURE CAPTIONS

Figure S1. The annual emissions and the relative changes over China from 2013 to 2060. The bottom plot shows China's anthropogenic emissions of selected species for 2013, 2020, 2035, and 2060, and the upper plot shows the relative changes between years. The species include NH_3, SO_2, NO_X BC, OC, dust, primary $PM_{2.5}$, NMVOCs, and CO. The emission data for 2013 and 2020 are obtained from MEIC, and those for 2035 and 2060 are obtained from DPEC (the on-time peak-net zero-clean air scenario).

Figure S2. Names and locations of provinces (grouped in seven regions).

Figure S3. Source-receptor matrices showing the annual $PM_{2.5}$-related marginal premature deaths for 31 × 31 province attributable to a 10% growth of emissions by sector (agriculture, industry, power, residential, and transportation) for (a) 2013, (b) 2020, and (c) 2035. Provinces are grouped into seven regions (see Supplementary Fig. S2). The top-right percentage of each subplot represents the fraction of cross-provincial exchange to the marginal premature deaths of the sector.

Figure S4. Source-receptor matrices showing the annual $PM_{2.5}$-related marginal premature deaths for 31 × 31 province attributable to a 10% growth of emissions by precursor species (NH_3, SO_2, NO_X, and primary $PM_{2.5}$) for (a) 2013, (b) 2020, and (c) 2035. Provinces are grouped into seven regions (see Supplementary Fig. S2). The top-right percentage of each subplot represents the fraction of cross-provincial exchange to the marginal premature deaths for the species.

Figure S5. Source-receptor matrices showing the annual ozone-related marginal premature deaths for 31 × 31 province attributable to a 10% growth of NOx emissions. (a) The matrices for 2013, 2020 and 2035 and (b) the differences between years. Provinces are grouped into seven regions (see Supplementary Fig. S2).

Figure S6. Source-receptor matrices of annual ozone-induced marginal premature deaths for 31 × 31 provinces attributable to a 10% growth of emissions by sector for (a) 2013, (b) 2020 and (c) 2035. Provinces are grouped into seven regions (see Supplementary Fig. S2).

Figure S7. The same as Figure S5 but attributable to a 10% growth of NMVOCs emissions. Provinces are grouped into seven regions (see Supplementary Fig. S2).

Figure S8. Comparisons of simulated $PM_{2.5}$ and ozone with corresponding observations over China for 2013 and 2020. (a) for $PM_{2.5}$ concentration ($\mu g\ m^{-3}$). (b) for maximum daily 8-h average (MDA8) ozone concentration (ppbv). R, OBS, SIM, and NMB indicate the correlation coefficient, observation, simulation, and normalized mean bias, respectively. The spatial distribution of average $PM_{2.5}$ and MDA8 ozone concentrations during the research period are shown in the left. The background indicates the simulated concentrations with GEOS-Chem forward model and circles indicate the observed concentrations released by MEE or TAP. The scattered $PM_{2.5}$ and ozone concentration data are shown in the right, respectively. The red lines indicate the linear regression lines.

Figure S9. Comparisons of simulated SNA with corresponding observations over China for 2013 and 2020. Black and red dotted lines represent the observations from TAP and simulations with GEOS-Chem forward model. The spatial simulated and observed comparisons are shown as inset. R, OBS, and SIM indicate the correlation coefficient, observation, and simulation, respectively.

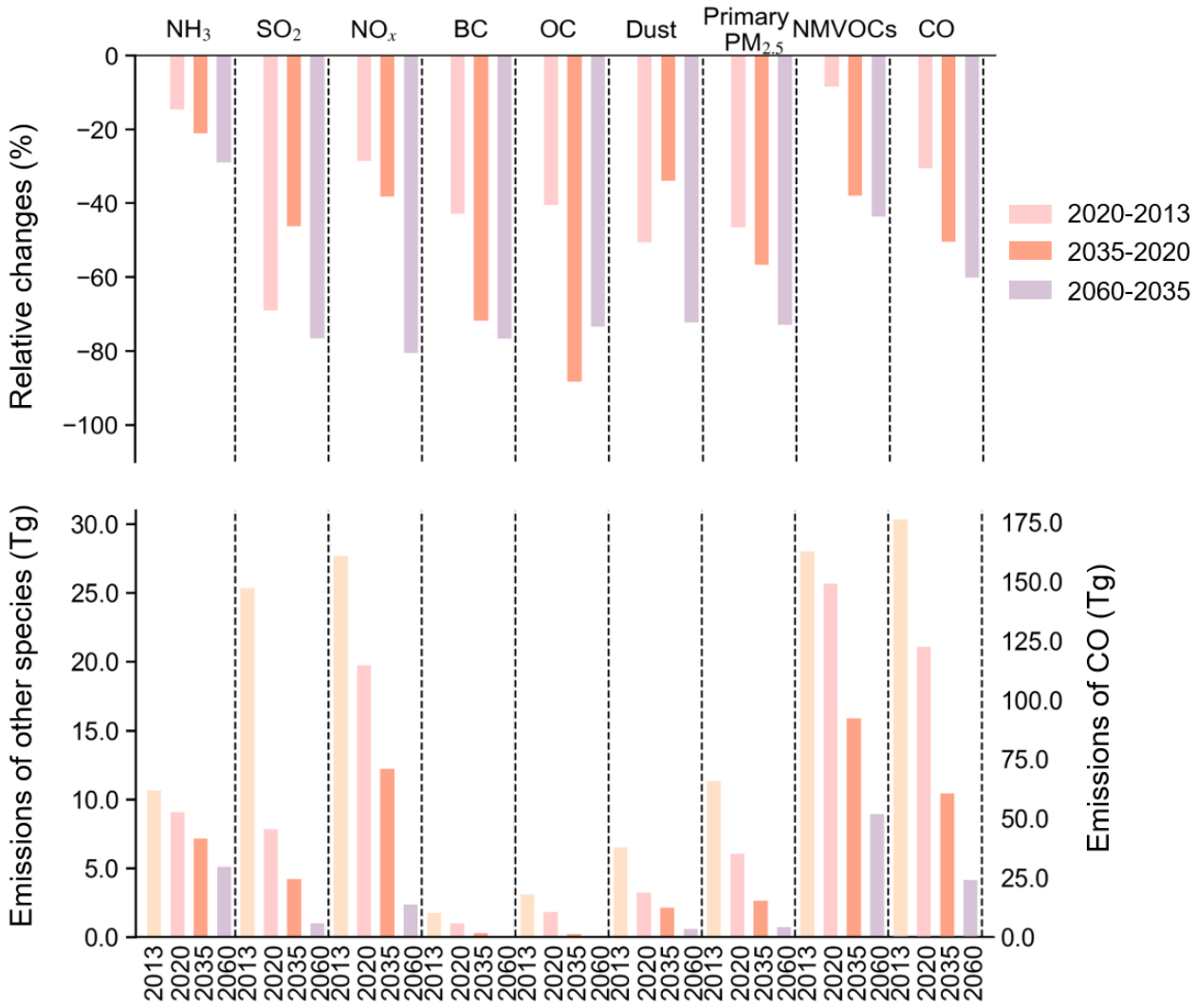

Figure S1. The annual emissions and the relative changes over China from 2013 to 2060. The bottom plot shows China's anthropogenic emissions of selected species for 2013, 2020, 2035, and 2060, and the upper plot shows the relative changes between years. The species include NH_3, SO_2, NO_X BC, OC, dust, primary $PM_{2.5}$, NMVOCs, and CO. The emission data for 2013 and 2020 are obtained from MEIC, and those for 2035 and 2060 are obtained from DPEC (the on-time peak-net zero-clean air scenario).

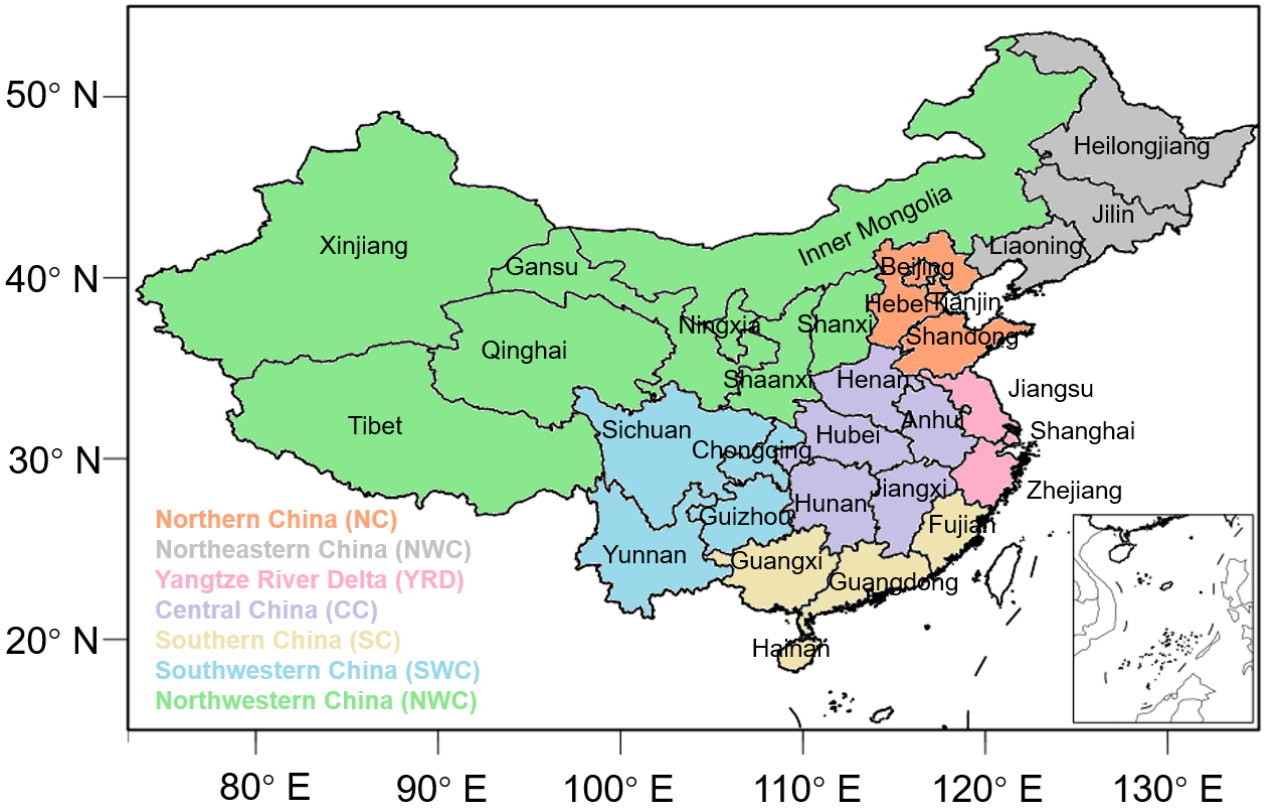

Figure S2. Names and locations of provinces (grouped in seven regions).

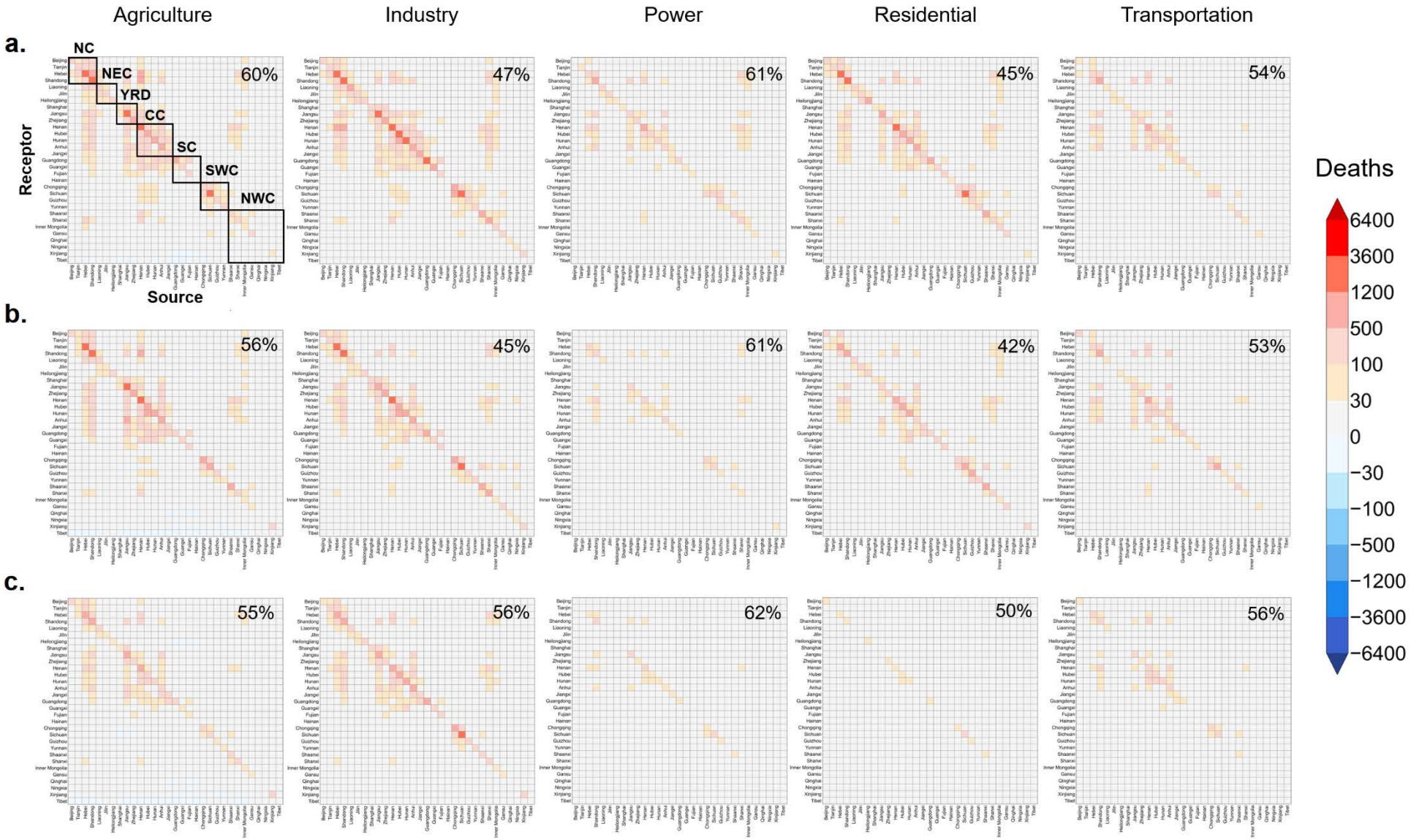

Figure S3. Source-receptor matrices showing the annual $PM_{2.5}$-related marginal premature deaths for 31 × 31 province attributable to a 10% growth of emissions by sector (agriculture, industry, power, residential, and transportation) for (a) 2013, (b) 2020, and (c) 2035. Provinces are grouped into seven regions (see Supplementary Fig. S2). The top-right percentage of each subplot represents the fraction of cross-provincial exchange to the marginal premature deaths of the sector.

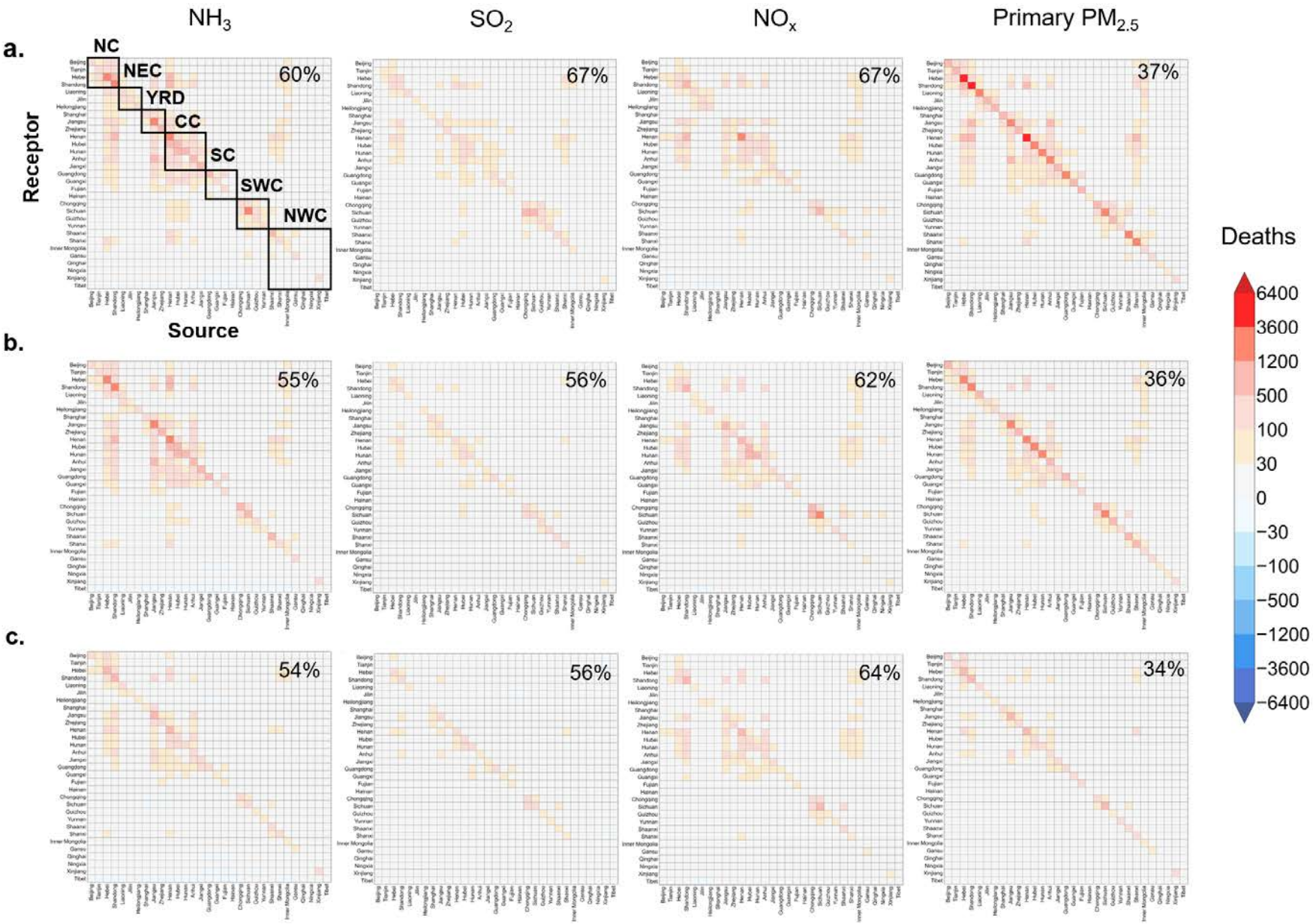

Figure S4. Source-receptor matrices showing the annual $PM_{2.5}$-related marginal premature deaths for 31 × 31 province attributable to a 10% growth of emissions by precursor species (NH_3, SO_2, NO_X, and primary $PM_{2.5}$) for (a) 2013, (b) 2020, and (c) 2035. Provinces are grouped into seven regions (see Supplementary Fig. S2). The top-right percentage of each subplot represents the fraction of cross-provincial exchange to the marginal premature deaths for the species.

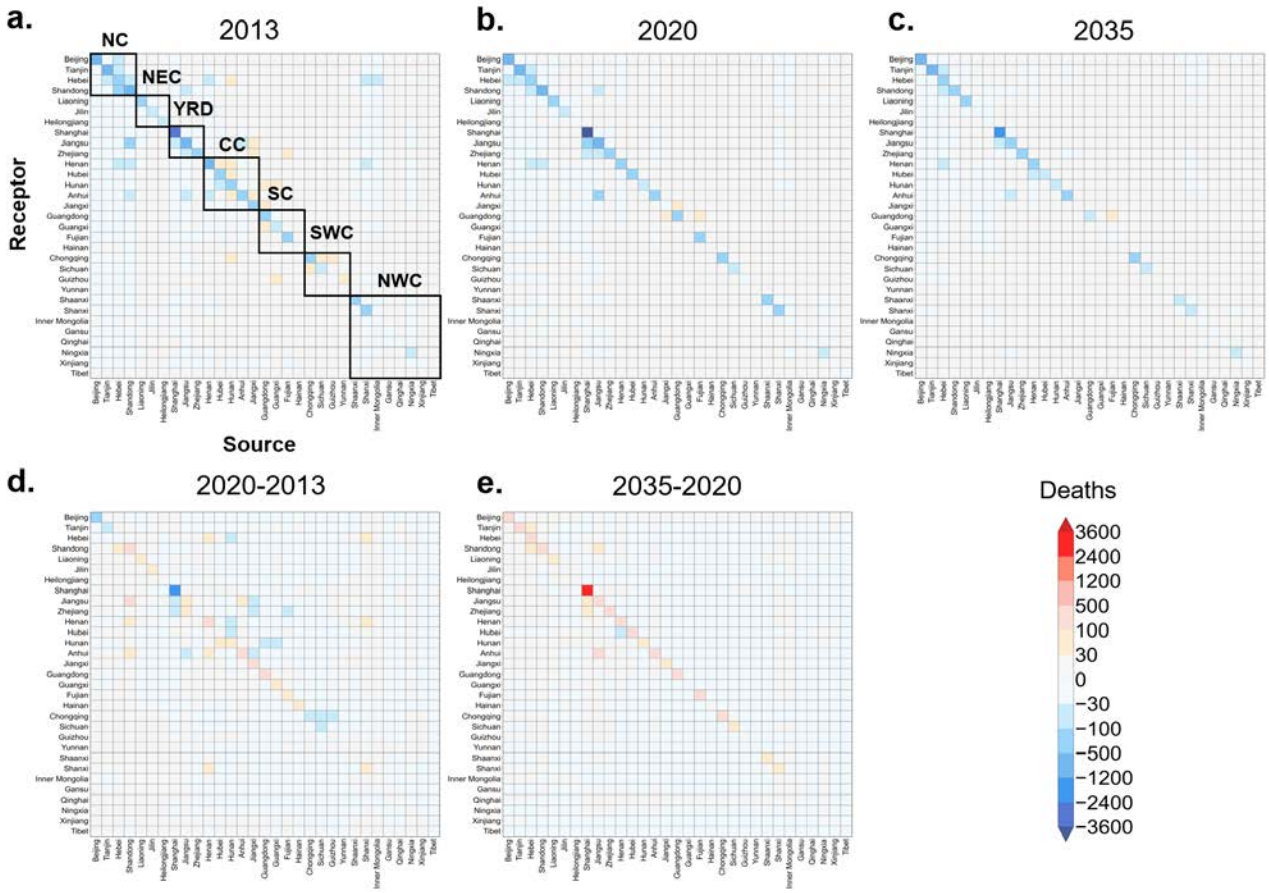

Figure S5. Source-receptor matrices showing the annual ozone-related marginal premature deaths for 31 × 31 province attributable to a 10% growth of NOx emissions. (a) The matrices for 2013, 2020 and 2035 and (b) the differences between years. Provinces are grouped into seven regions (see Supplementary Fig. S2).

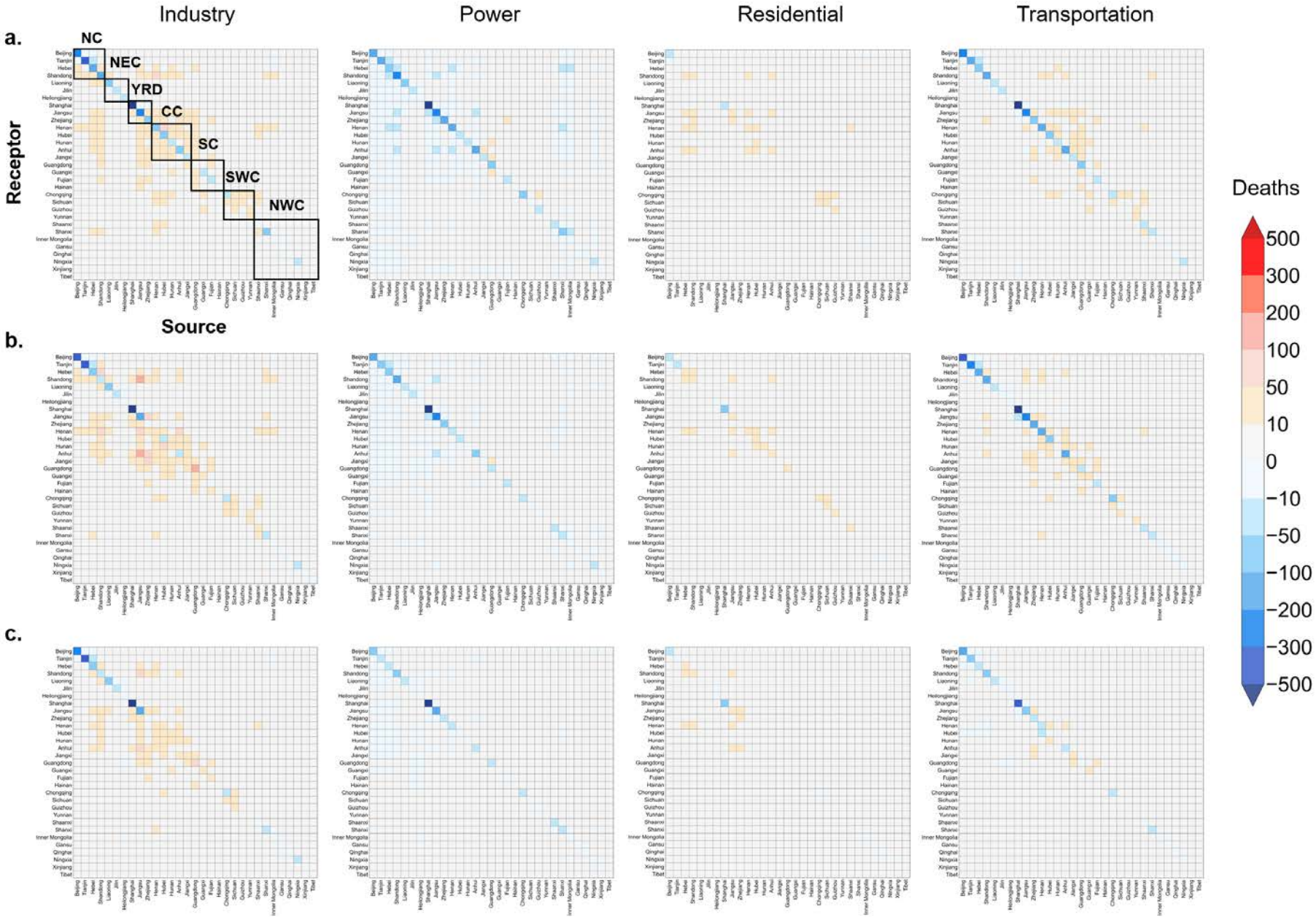

Figure S6. Source-receptor matrices of annual ozone-induced marginal premature deaths for 31 × 31 provinces attributable to a 10% growth of emissions by sector for (a) 2013, (b) 2020 and (c) 2035. Provinces are grouped into seven regions (see Supplementary Fig. S2).

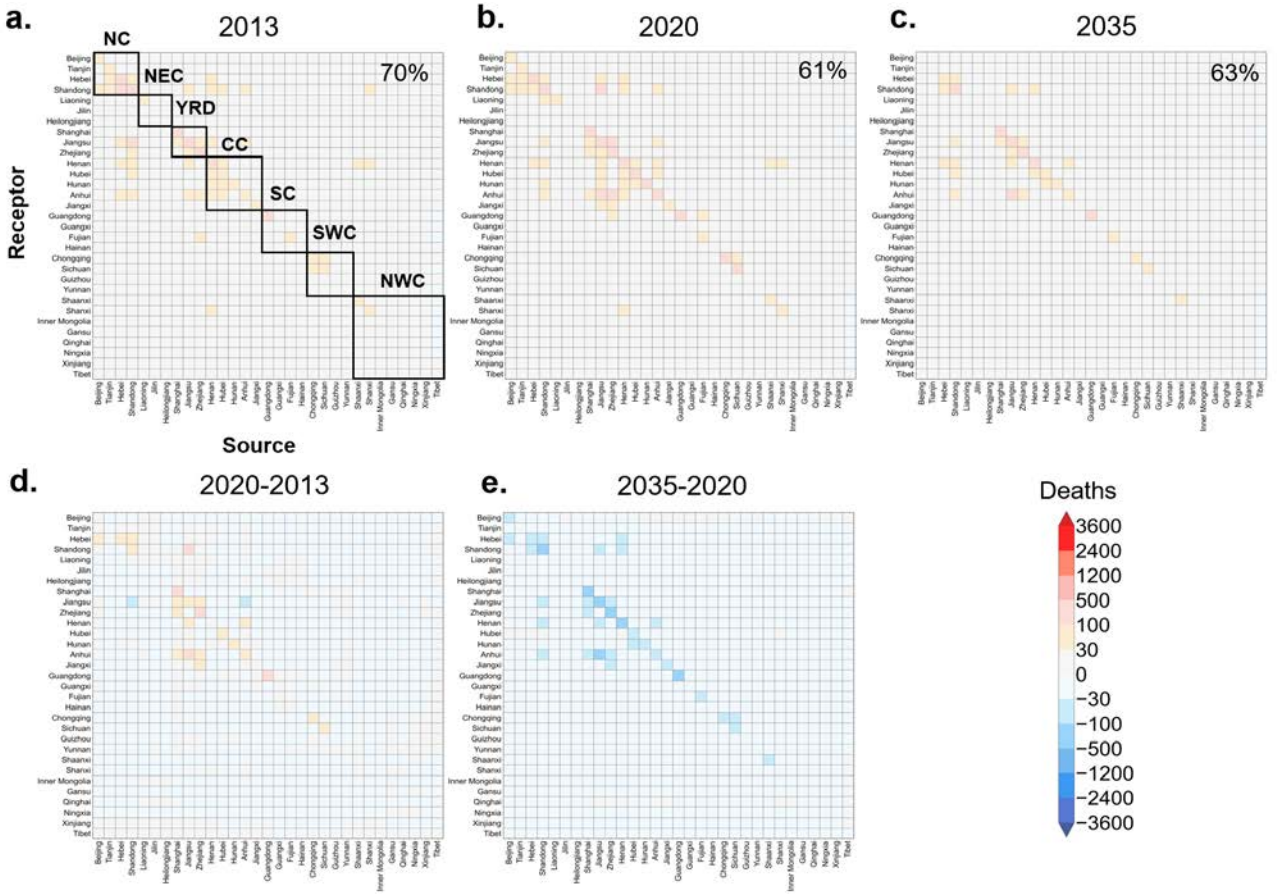

Figure S7. The same as Figure S5 but attributable to a 10% growth of NMVOCs emissions. Provinces are grouped into seven regions (see Supplementary Fig. S2).

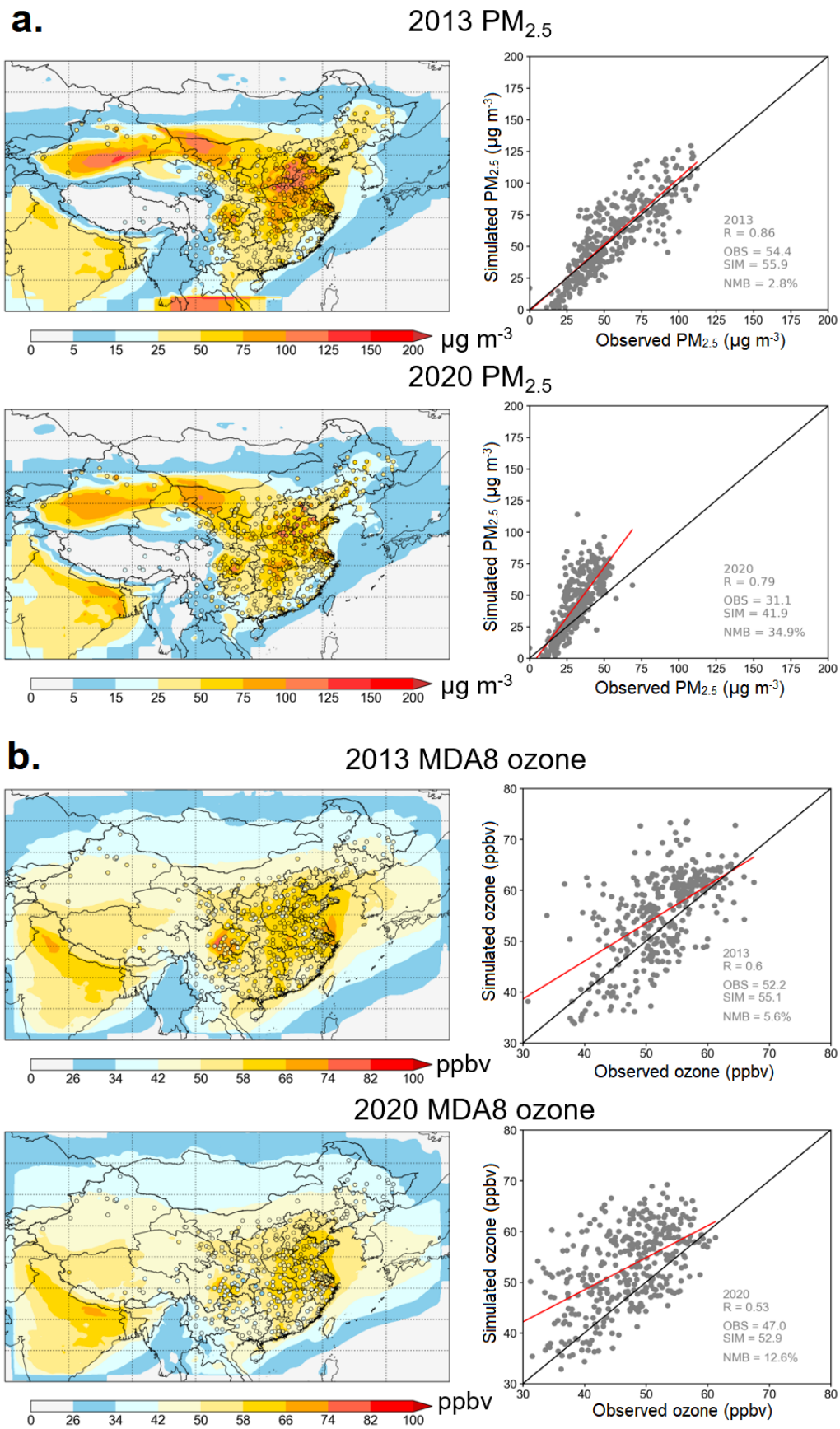

Figure S8. Comparisons of simulated $PM_{2.5}$ (a) and maximum daily 8-h average (MDA8) ozone concentration (b) with corresponding observations over China for 2013 and 2020. The spatial distribution of average $PM_{2.5}$ and MDA8 ozone concentrations are shown in the left. The background indicates the simulated concentrations with GEOS-Chem forward model and circles indicate the observed concentrations released by MEE or TAP. The scattered $PM_{2.5}$ and ozone concentration data are shown in the right. The red lines indicate the linear regression lines. OBS, SIM, R, and NMB indicate the observed and simulated concentration, correlation coefficient between them, and normalized mean bias, respectively.

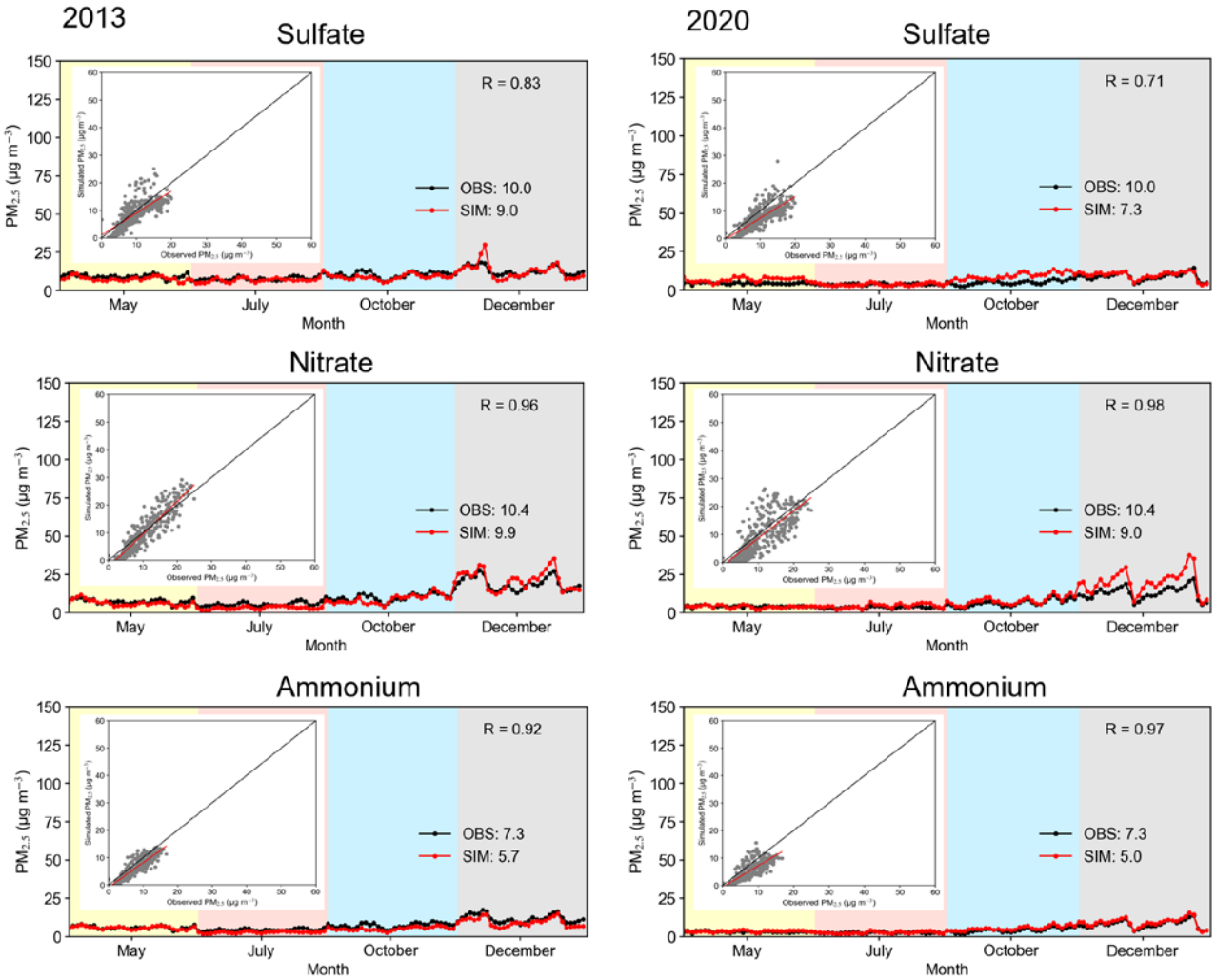

Figure S9. Comparisons of simulated SNA with corresponding observations over China for 2013 and 2020. Black and red dotted lines represent the daily concentrations of nationwide average from TAP observation and GEOS-Chem forward simulation, respectively. The spatial correlations of observed and simulated annual concentration at the resolution of 0.25°×0.3125° are shown in the inner boxes. OBS, SIM, and R indicate the daily concentration from TAP observation, GEOS-Chem forward simulation, and correlation coefficient between them, respectively.

Table 1. Five main sectors with divided source categories and corresponding abbreviations used in this study.

Sector	Source categories	Abbreviations
Agriculture	–	agriculture
Industry	combustion	industry_combustion
	iron & steel production	industry_iron_steel
	cement production	industry_cement
	coking	industry_coking
	other industrial process of production	industry_other_process
	paint for architecture	paint_architecture
	paint for vehicle production	paint_vehicle
	paint for wood	paint_wood
	paint for other industrial processes	paint_other_industry
	printing	printing
	pharmaceutical production	pharmaceutical_production
	other solvent use	other_solvent_use
Power	–	power
Residential	rural energy use	residential_rural
	urban energy use	residential_urban
	waste treatment	waste
Transportation	on-road diesel vehicles	onroad_diesel
	on-road gasoline vehicles	onroad_gas
	motorcycle	motorcycle
	off-road traffic	offroad

Table 2. The proportions (%) of cross-provincial transport to national $PM_{2.5}$-related marginal premature deaths for 31 provinces over China for 2013, 2020, 2035 and the 3-year averages.

Seven regions	Province	2013	2020	2035	average
Northern China (NC)	Beijing (BJ)	71	67	76	71
	Tianjin (TJ)	67	75	73	72
	Hebei (HeB)	44	45	42	44
	Shandong (SD)	47	48	50	48
Northeastern China (NWC)	Liaoning (LN)	44	45	48	46
	Jilin (JL)	51	62	70	61
	Heilongjiang (HLJ)	41	44	55	47
Yangtze River Delta (YRD)	Shanghai (SH)	67	70	69	69
	Jiangsu (JS)	54	51	52	52
	Zhejiang (ZJ)	61	56	53	57
Central China (CC)	Henan (HeN)	56	56	58	57
	Hubei (HuB)	58	54	61	58
	Hunan (HuN)	61	61	68	63
	Anhui (AH)	62	62	66	63
	Jiangxi (JX)	63	67	70	67
Southern China (SC)	Guangdong (GD)	55	64	64	61
	Guangxi (GX)	67	75	76	73
	Fujian (FJ)	51	47	53	51
	Hainan (HaN)	80	85	88	84
Southwestern China (SWC)	Chongqing (CQ)	48	37	33	40
	Sichuan (SC)	39	33	33	35
	Guizhou (GZ)	55	45	58	53
	Yunnan (YN)	44	42	41	42
Northwestern China (NWC)	Shaanxi (SaX)	41	28	25	31
	Shanxi (SX)	47	46	46	46
	Inner Mongolia (IM)	42	40	44	42
	Gansu (GS)	46	35	38	40
	Qinghai (QH)	31	29	26	29
	Ningxia (NX)	48	38	40	42
	Xinjiang (XJ)	0	0	0	0
	Tibet (TB)	53	2	1	18