SUPPORTING INFORMATION for

Effectiveness of emission control to reduce $PM_{2.5}$ pollution of Central China during winter haze episodes under various potential synoptic controls

Yingying Yan [1#], Yue Zhou [2#], Shaofei Kong [1*], Jintai Lin [3], Jian Wu[1, 4], Huang Zheng [1, 4], Zexuan Zhang [1, 4], Yongqing Bai [2], Zhang Ling [2], Dantong Liu [5], Tianliang Zhao [6]

[1] Department of Atmospheric Sciences, School of Environmental Studies, China University of Geosciences, Wuhan, 430074, China
[2] Hubei Key Laboratory for Heavy Rain Monitoring and Warning Research, Institute of Heavy Rain, China Meteorological Administration, Wuhan 430205, China
[3] Laboratory for Climate and Ocean-Atmosphere Studies, Department of Atmospheric and Oceanic Sciences, School of Physics, Peking University, Beijing 100871, China
[4] Department of Environmental Science and Engineering, School of Environmental Studies, China University of Geosciences, Wuhan, 430074, China
[5] Department of Atmospheric Sciences, School of Earth Sciences, Zhejiang University, Hangzhou, Zhejiang, China
[6] School of Atmospheric Physics, Nanjing University of Information Science and Technology, Nanjing, 210044, China

Content

S1. Emissions in GEOS-Chem model

Global anthropogenic emissions of CO, NO_x and SO_2 in 2013-2014 are from EDGAR (Emission Database for Global Atmospheric Research) v4.2 with a resolution of 0.1° × 0.1°. Monthly global anthropogenic emission of non-methane volatile organic compounds (NMVOCs) are taken from RETRO (REanalysis of the TROpospheric chemical composition) in the year of 2000 with the grid resolution of 0.5° × 0.5°. The monthly emission data of biomass burning comes from GFED4 (Global Fire Emissions Database version 4). Other natural source emissions, such as NO_x from lightning and soil and NMVOCs from biogenic emissions, are calculated on-line by parameterization based on meteorological conditions in the simulations. The parameterization of soil NO_x emission follows Hudman et al. (2012). The NMVOCs biogenic emissions are calculated by MEGAN (Model of Emissions of Gases and Aerosols from Nature) v2.1 according to the monthly averaged MODIS (MODerate resolution Imaging Spectroradiometer) leaf area index.

S2. Optimation in GEOS-Chem model

(1) Optimize $PM_{2.5}$ emissions

The primary particulate matter emitted by human activities is an important source of $PM_{2.5}$ (Pui et al., 2014). Only natural emission sources of $PM_{2.5}$, such as dust and sea salt, are considered in the standard version of GEOS-Chem v11-01 (Yan et al., 2019). According to the emission inventory of MEIC in 2013-2014 and SEEA, this study adds the $PM_{2.5}$ primary anthropogenic emissions in the model.

(2) Increase the proportion of sulfate primary emission

Human activities would lead to the primary emission of sulfate (Fu et al., 2013). At present, there is no global/regional sulfate emission inventory, so the model can not grasp the primary emission of sulfate very well. According to previous observations, the primary emission concentration of sulfate is about 3% of SO_2 emission concentration (Fu et al., 2013). Thus the primary emission of sulfate in the model is

simply parameterized to 3% of SO_2 emission. However, the latest observation shows that the primary emission of sulfate in China is relatively high (Yan et al., 2020). In addition, the primary emission of SO_3 and its conversion to sulfate are not considered in the model, so we increase the primary emission proportion of sulfate to 4.5% of SO_2 emission.

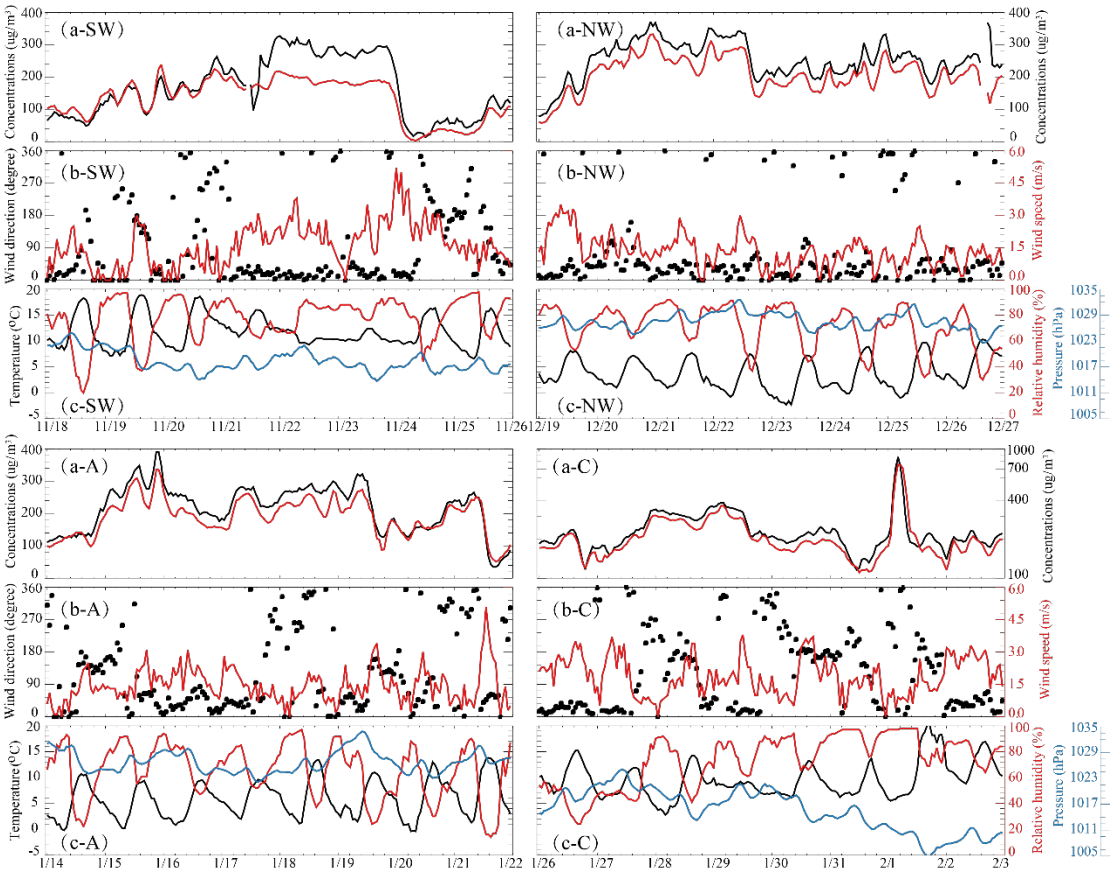

Figure S1 (a) Modeled (red lines) and observed (black lines) hourly $PM_{2.5}$ concentration ($\mu g/m^3$) at Jingzhou during the four typical heavy pollution processes, forced by SW-type, NW-type, A-type and C-type circulation, respectively. (b) Observed wind speed (red line) and wind direction (black dots). (c) Obseved temperature (black line), relative humidity (red line) and sea level pressure (blue line).

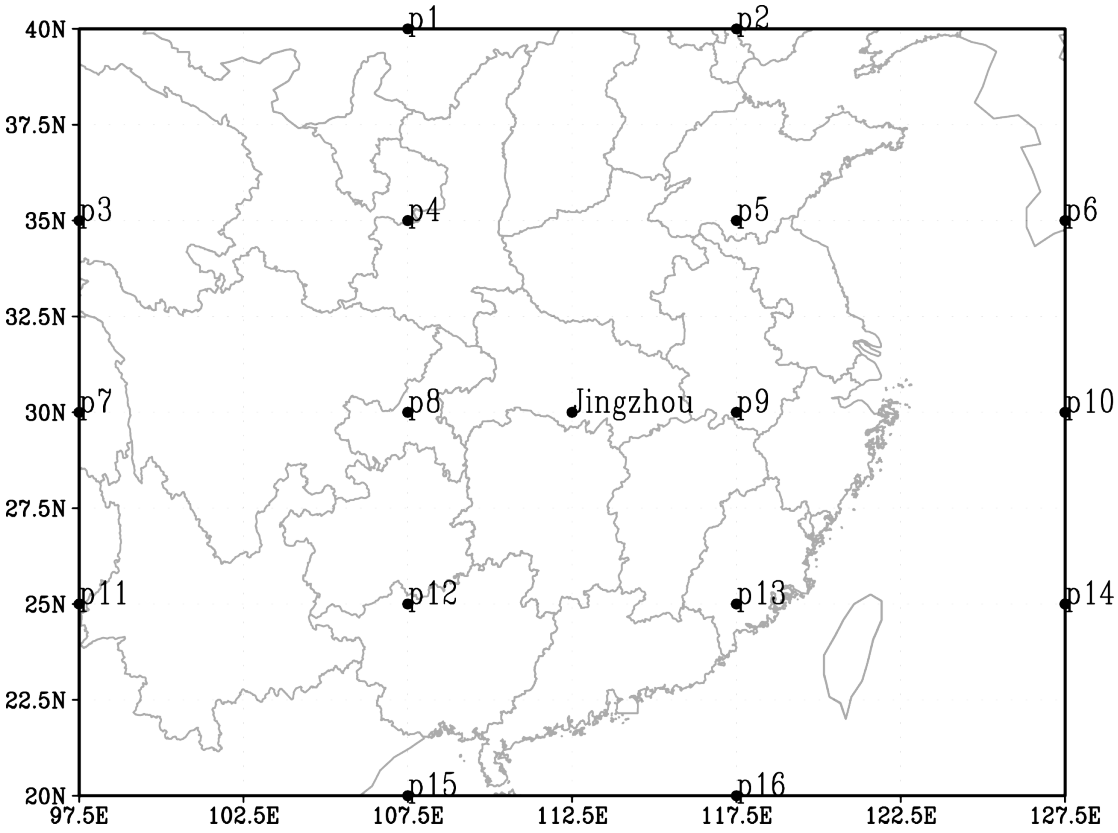

Figure S2 Location of the grid points used in circulation classification calculation

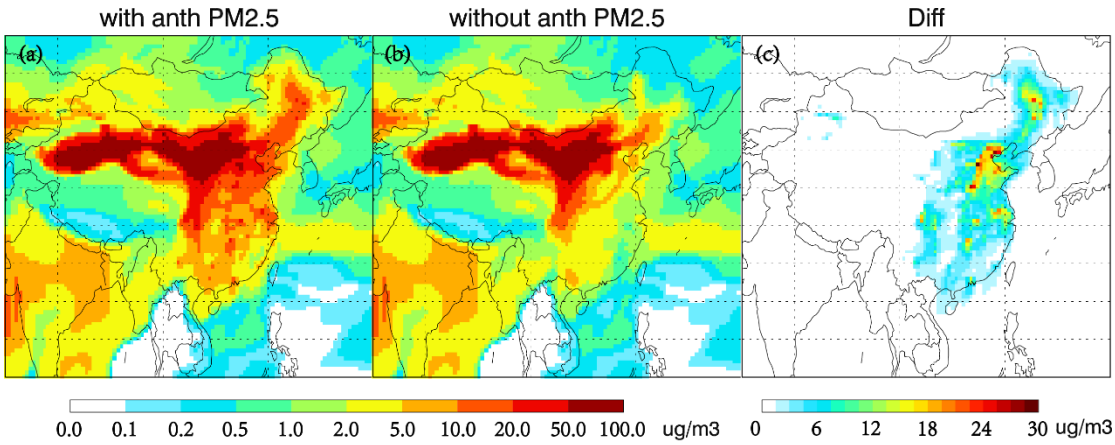

Figure S3 Modeled $PM_{2.5}$ concentrations with and without $PM_{2.5}$ primary anthropogenic emissions. Also shown is the difference between the two simulations.

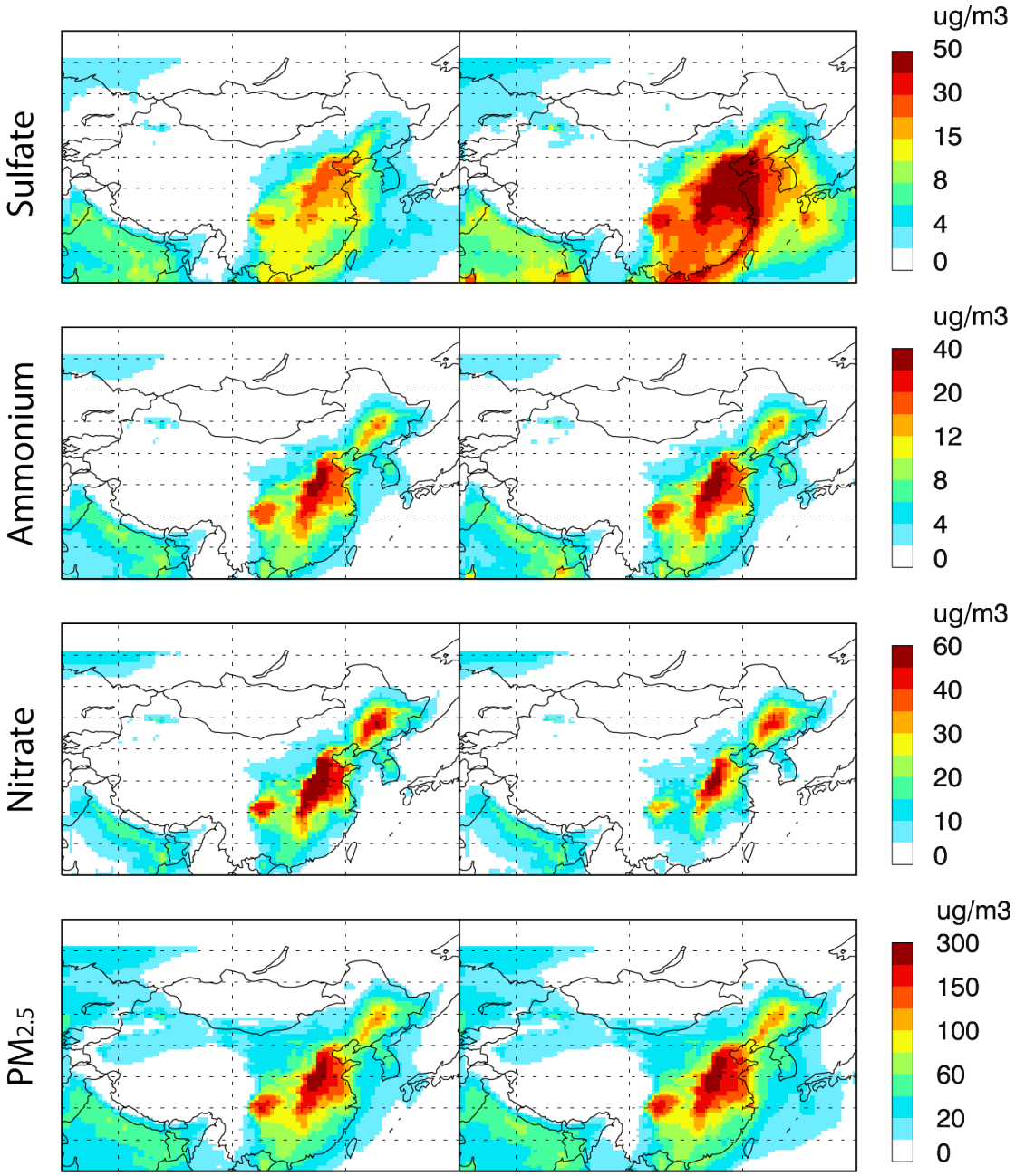

Figure S4 Modeled $PM_{2.5}$, sulfate, nitrate and ammonium concentrations in standard GEOS-Chem v11-01 (left column) and in optimized model version (right column).

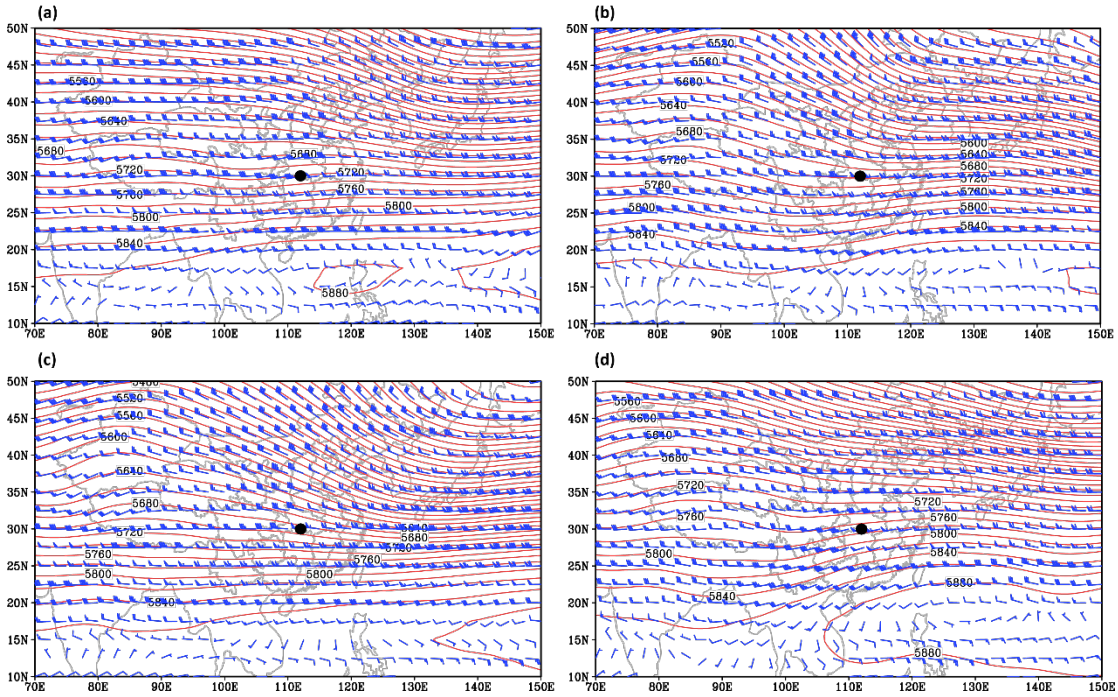

Figure S5 Spatial distribution of 500 hPa geopotential height and wind vector for SW-type (a), NW-type (b), A-type (c) and C-type (d) synoptic control averaged over 2013-2018.

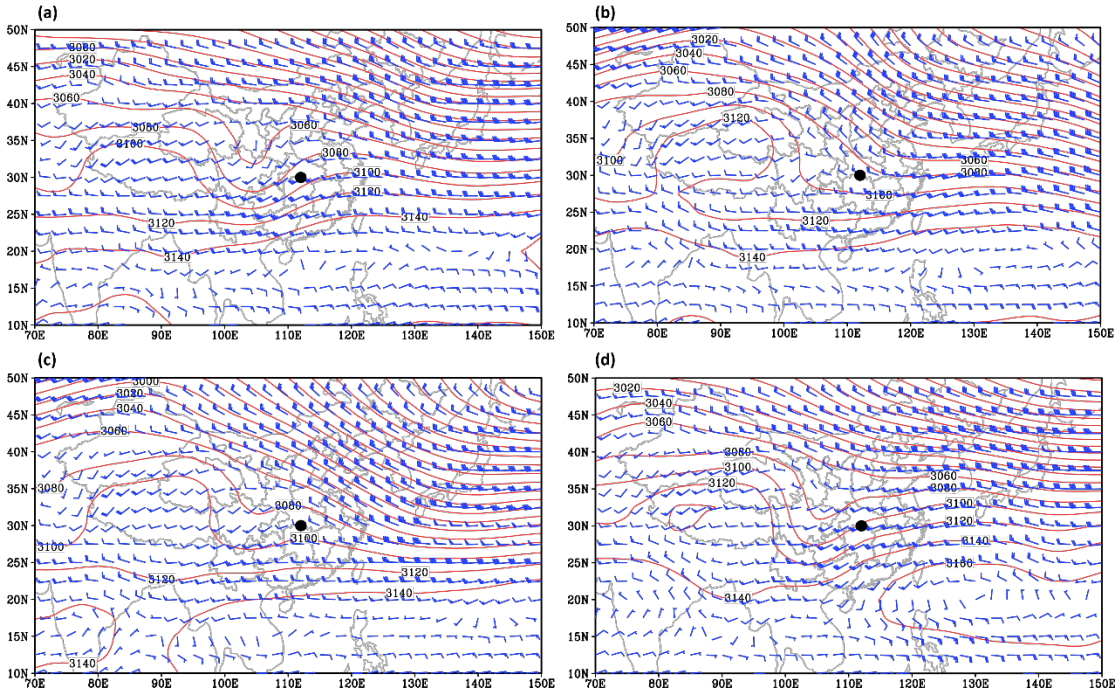

Figure S6 Spatial distribution of 700 hPa geopotential height and wind vector for SW-type (a), NW-type (b), A-type (c) and C-type (d) synoptic control averaged over 2013-2018.

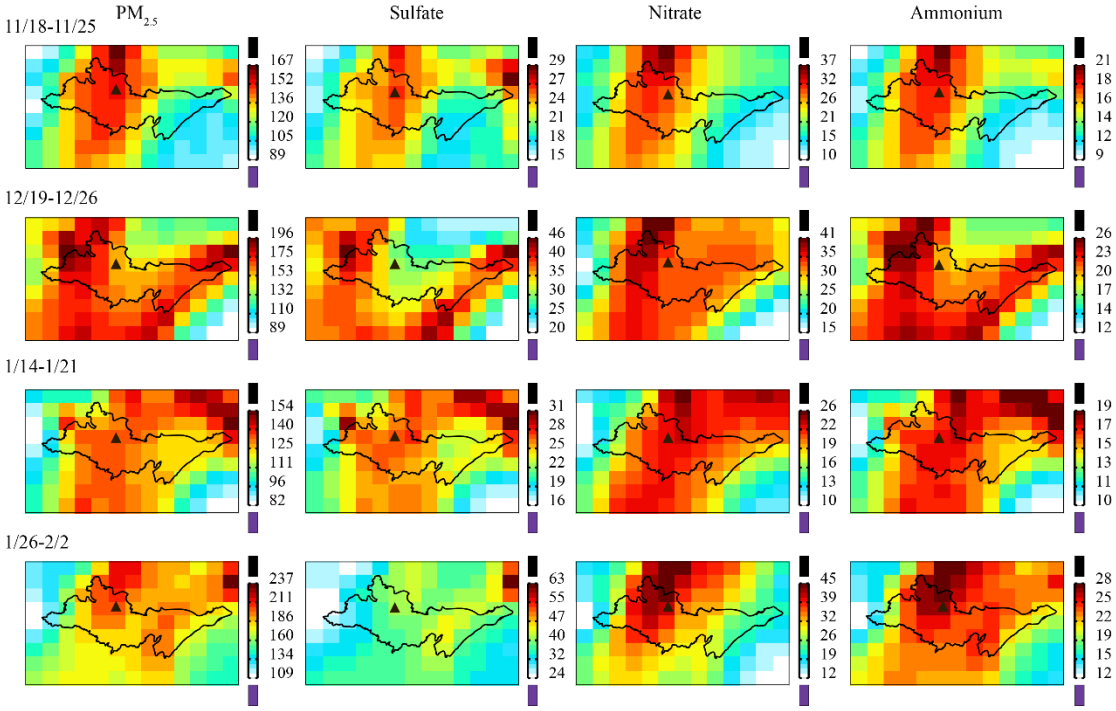

Figure S7 Spatial distribution of $PM_{2.5}$, sulfate, nitrate and ammonium concentrations averaged in four typical heavy pollution processes over Jingzhou simulated by GEOS-Chem control simulation ($\mu g/m^3$).

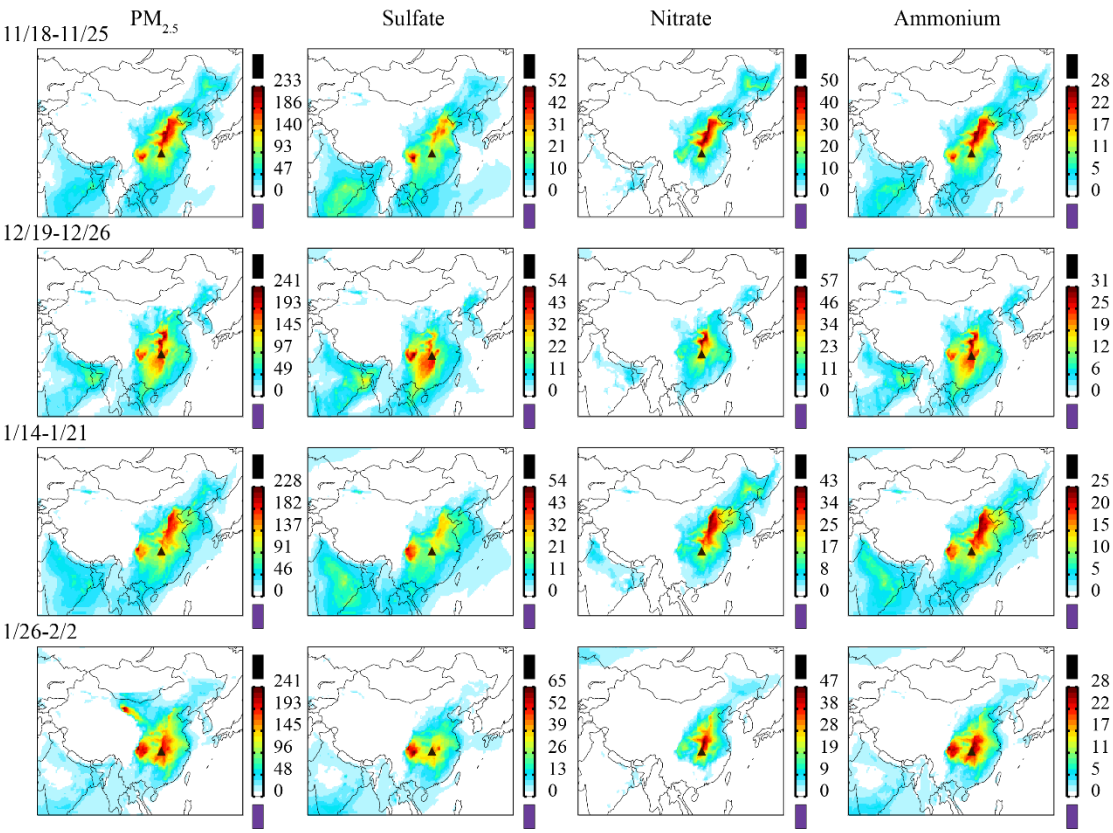

Figure S8 Spatial distribution of $PM_{2.5}$, sulfate, nitrate and ammonium concentrations averaged in four typical heavy pollution processes over China simulated by GEOS-Chem control simulation ($\mu g/m^3$).

Table S1 Anthropogenic and natural source emission inventories adopted in the GEOS-Chem modelling of this study

Region	Abbreviation	Description	Resolution	Year	Species	Reference
Anthropogenic emission inventory						
Global	EDGAR	EDGAR v4.2 anthropogenic + biofuel	0.1°× 0.1°, monthly	2013-2014	NOx, SO_2, SO_4^{2-}, CO, NH_3	http://edgar.jrc.ec.europa.eu/overview.php?v=42
Global	BOND	BOND biofuel + anthropogenic BC + OC emissions	1°×1°, monthly	2000	BC and OC	Bond et al. (2007)
Global	RETRO	RETRO anthropogenic + biofuel	0.5°×0.5°, monthly	2000	NMVOCs[1] except C_2H_6 and C_3H_8	ftp://ftp.retro.enes.org/pub/emissions/aggregated/anthro/0.5x0.5/2000/
Global	SHIP	ICOADS ship emissions	1°×1°, monthly	2002	NO_x, SO_2, CO	Wang et al. (2008)
Global	AEIC	Aircraft emissions	1°×1°, monthly	2005	NO_x, SO_2, CO, NMVOCs[1], BC, OC	
Global	MEIC	MEIC inventory for China	0.25°×0.25°, monthly	2013-2014	NO_x, SO_2, CO, NMVOCs[1], NH_3	http://www.meicmodel.org/.
USA	NEI2011	US EPA NEI-2011 emission inventory	0.1°× 0.1°, monthly	2013-2014	NO_x, SO_2, CO, NMVOCs[1], NH_3, BC, OC	https://www.epa.gov/air-emissions-inventories
Europe	EMEP	EMEP	1°×1°, annual	2013-2014	NO_x, SO_2, CO	Auvray and Bey (2005)

Central China	SEEA	SEEA	0.1°× 0.1°, monthly	2014	NO_x, SO_2, CO, NH_3, VOCs	
Biomass burning emission inventory						
Global	GFED4	GFED4 biomass burning inventory	0.25°× 0.25°, monthly	2013-2014	NO_x, SO_2, CO, NMVOCs, NH_3, BC, OC	http://www.globalfiredata.org, Giglio e al. (2013)
Biogenic emission inventory						
Global	MEGAN	MEGAN v2.1 biogenic emissions	—	2013-2014	ISOP, monoterpenes, sesquiterpenes, MOH, ACET, ETOH, CH_2O, ALD_2, HCOOH, C_2H_4, TOLU, PRPE	Guenther et al. (2012)
Other natural emission inventory						
Global	SoilNOx	Emission of NO_x from soils and fertiliser use	—	2013-2014	NO	Hudman et al. (2012)
Global	LightNOx	NO_x from lightning	—	2013-2014	NO	Murray et al. (2012)

1. RETRO includes PRPE, ALK_4, ALD_2, CH_2O and MEK; in the CTM, MEK emissions are further allocated to MEK (25 %) and ACET (75 %). AEIC and MEIC include PRPE, C_2H_6, C_3H_8, ALK_4, ALD_2, CH_2O, MEK and ACET. NEI2011 includes PRPE, C_3H_8, ALK_4, CH_2O, MEK and ACET. EMEP includes PRPE, ALK_4, ALD_2 and MEK. Emissions of C_2H_6 outside Asia are from Xiao et al. (2008).

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