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Response to the First Referee

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Reviewer #1:

This paper by Yan et al. investigated the characteristics of winter haze episodes in Jingzhou of Central China under typical potential synoptic controls (PSCs) during November 2013-February 2014. Furthermore, they examined the contributions of local and transport of pollutants from surrounding regions to PM2.5 under different PSCs by applying the GEOS-Chem model with a high resolution. This work also studied the effectiveness of different emission control strategies in Jingzhou, Central China, and other surrounding regions under different PSCs, and highlights the importance of collaborative actions for PM2.5 mitigation under server haze pollution. In general, the study is well organized and worthy of publication. However, I have some specific comments that I feel deserve attention.

We thank the reviewer for comments, which have been incorporated to improve the manuscript.

Major comments

1. The writing should be improved before publication.

We thank the referee for this comment. We have made necessary corrections to grammar throughout the text (see details in the revision manuscript). We have polished the manuscript for all the authors.

2. The configuration of the model is vague. How many nested domains were applied in each simulation? What is the geographic coverage of each domain and the corresponding resolution? What are the emission inventories for each domain? A figure showing each nested domain is also highly recommended.

We thank the referee for this comment. We have added a figure in the revised file of supporting information to explain the geographic coverage of each domain and the corresponding resolution for GEOS_Chem global model (2° × 2.5°, providing boundary condition to nested model) and nested model (70°E-140°E, 15°S-55°N; 0.25° × 0.3125°). The emission inventories for each domain are shown in the revised Table S1 and Table S2. We also revised the description in the text of Sect. 2.3.

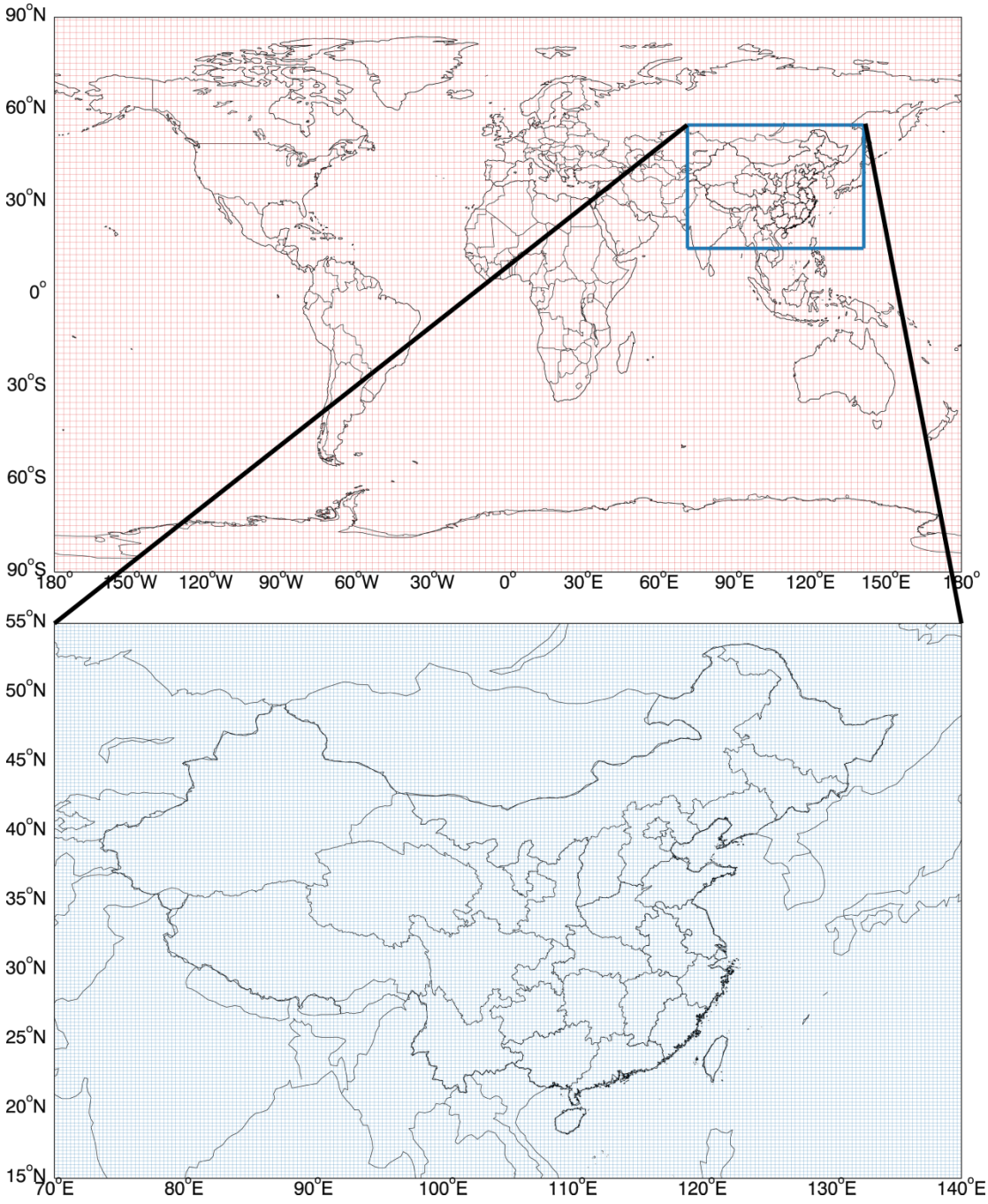

Figure S3 The geographic coverage of each domain and the corresponding resolution for GEOS_Chem global model (2° × 2.5°) and nested model (70°E-140°E, 15°S-55°N; 0.25° × 0.3125°).

Table S1 Anthropogenic and natural source emission inventories adopted in the GEOS-Chem global 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	
China	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)
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 et 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).

Table S2 Anthropogenic and natural source emission inventories adopted in the GEOS-Chem nested modelling of this study

Region	Abbreviation	Description	Resolution	Year	Species	Reference
Anthropogenic emission inventory						
Non-China	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
Nested domain	BOND	BOND biofuel + anthropogenic BC + OC emissions	1°×1°, monthly	2000	BC and OC	Bond et al. (2007)
Non-China	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/
Nested domain	SHIP	ICOADS ship emissions	1°×1°, monthly	2002	NO_x, SO_2, CO	Wang et al. (2008)

Nested domain	AEIC	Aircraft emissions	1°×1°, monthly	2005	NO_x, SO_2, CO, NMVOCs[1], BC, OC	
China	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/.
Central China	SEEA	SEEA	0.1°× 0.1°, monthly	2017	NO_x, SO_2, CO, NH_3, VOCs	
Biomass burning emission inventory						
Nested domain	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						
Nested domain	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						
Nested domain	SoilNOx	Emission of NO_x from soils and fertiliser use	—	2013-2014	NO	Hudman et al. (2012)
Nested domain	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)

3. The circulation classification is the basis of all the analysis. Why did you choose the Lamb-Jenkension method? What are the advantages of this method compared to the ones used in other studies such as Chang and Zhan, 2017, Dai et al., 2021, etc.?

We thank the referee for this comment. We have reviewed the advantages of Lamb-Jenkension method with respect to the ones used in other studies in the revised Sect. 2.2: "Compared to the objective classification method PCA used in some studies (Chang and Zhan, 2017, Dai et al., 2021), this Lamb-Jenkension method is a combination of subjective and objective methods. After the objective judgment of the circulation, we also make subjective considerations to overcome the weaknesses of their respective, leading to better synoptic significance. Many works of circulation classification have used the Lamb-Jenkension method and reported that the analysis can well respond to the classification results (Philipp et al., 2016;Santurtun et al., 2015;Pope et al., 2015;Russo et al., 2014;Pope et al., 2014;Trigo and DaCamara, 2000)."

Philipp, A., Beck, C., Huth, R., and Jacobeit, J.: Development and comparison of circulation type classifications using the COST 733 dataset and software, International Journal of Climatology, 36, 2673-2691, 10.1002/joc.3920, 2016.

Pope, R. J., Savage, N. H., Chipperfield, M. P., Arnold, S. R., and Osborn, T. J.: The influence of synoptic weather regimes on UK air quality: analysis of satellite column NO_2, Atmospheric Science Letters, 15, 211-217, 10.1002/asl2.492, 2014.

Pope, R. J., Savage, N. H., Chipperfield, M. P., Ordonez, C., and Neal, L. S.: The influence of synoptic weather regimes on UK air quality: regional model studies of tropospheric column NO_2, Atmospheric Chemistry and Physics, 15, 11201-11215, 10.5194/acp-15-11201-2015, 2015.

Russo, A., Trigo, R. M., Martins, H., and Mendes, M. T.: NO_2, PM_{10} and O_3 urban concentrations and its association with circulation weather types in Portugal, Atmospheric Environment, 89, 768-785, 10.1016/j.atmosenv.2014.02.010, 2014.

Santurtun, A., Carlos Gonzalez-Hidalgo, J., Sanchez-Lorenzo, A., and Teresa Zarrabeitia, M.: Surface ozone concentration trends and its relationship with weather types in Spain (2001-2010), Atmospheric Environment, 101, 10-22, 10.1016/j.atmosenv.2014.11.005, 2015.

Trigo, R. M., and DaCamara, C. C.: Circulation weather types and their influence on the precipitation regime in Portugal, International Journal of Climatology, 20, 1559-1581, 10.1002/1097-0088(20001115)20:13<1559::aid-joc555>3.0.co;2-5, 2000.

4. The validation of model performances is very weak. The bias of the modeled PM2.5 in Jingzhou can be as high as more than 100 μg/m3, what are the possible reasons? The authors simply claimed the uncertainties in emissions, meteorology, and chemistry might cause this discrepancy without any details. What are the amount of the PM2.5 precursors emitted in this study and how are the values compared to the published literature? How about the meteorological parameters used by the model vs. observations? The authors claimed an

improvement in sulfate by the increase in primarily emitted sulfate in the model, how is that compared with observations? They also analyzed the changes in the chemical composition of PM2.5 under different typical PSCs without examination of the model performances in the base case.

Thanks for this query and suggestion, which are valuable for us to improve this work.

In order to better evaluate the GEOS-Chem model performances, the spatial distribution of $PM_{2.5}$ concentrations averaged over the four typical heavy pollution processes simulated by the control (CON) simulation are compared with the observations (a total of 633 sites) from Ministry of Ecology and Environment of China (http://www.mee.gov.cn/) (revised Fig. 6). Similar to the underestimation in $PM_{2.5}$ at Jingzhou, the underestimation is on a national scale when compared with the MEE observations, with a bias of -29.3 $\mu g/m^3$, -18.7 $\mu g/m^3$, -39.0 $\mu g/m^3$ and -21.4 $\mu g/m^3$ on average for SW-type, NW-type, A-type and C-type synoptic pattern, respectively (Fig. 6).

In order to explain the causes of the model discrepancy, we have added Table S3 to show the observed (modeled) meteorological conditions averaged over these four pollution episodes controlled by SW-type, NW-type, A-type and C-type synoptic pattern, respectively. There is an overestimate in temperature and wind speed and an underestimate in humidity, which can partly contribute to the underestimation of modeled $PM_{2.5}$ concentrations. In addition, anthropogenic emissions for $PM_{2.5}$ precursors used here are for the year 2017 over Central China from our newly developed SEEA inventory (Table S4). From 2013 to 2017, anthropogenic NO_x, SO_2, and primary $PM_{2.5}$ emissions in Central China have declined substantially (Table S4), due to the implementation of stringent emission control measures for the 12^{th}-13^{th} Five-Year Plans (Zheng et al., 2018). The anthropogenic emissions biases may affect our simulations and $PM_{2.5}$ attribution results to some extent.

We have no observations of the chemical compositions of $PM_{2.5}$. In order to examine the model performances in the $PM_{2.5}$ chemical compositions, we have added Table 4 to review the reported concentrations of $PM_{2.5}$ and the three inorganic salts (sulfate, nitrate and ammonium) in other cities. The contributions of sulfate, nitrate and ammonium are 9.1%-31.9%, 5.7%-32.1% and 5.9%-13.3%, respectively. In the CON simulation, the fractions of each inorganic salt to $PM_{2.5}$ for these four typical heavy pollution processes are shown in revised Fig. S10, which are comparable to the previous results (Table 4).

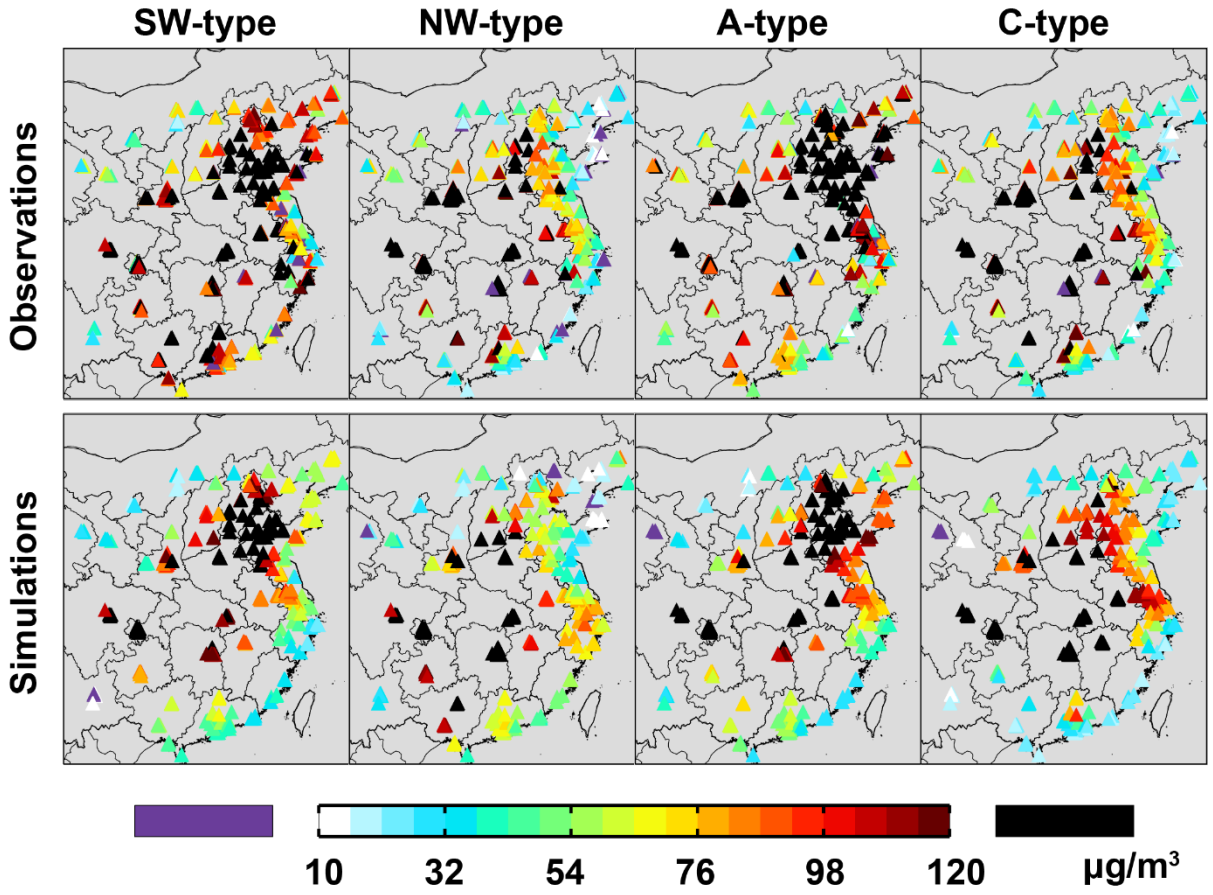

Figure 6 Spatial distribution of observed (top row) and modeled (bottom row, by CON case) $PM_{2.5}$ concentrations (μg/m^3) averaged over four severe pollution episodes controlled by SW-type (first column), NW-type (second column), A-type (third column) and C-type (forth column) synoptic pattern, respectively.

Table S3. The observed (modeled) meteorological conditions at Jingzhou averaged over these four pollution episodes controlled by SW-type, NW-type, A-type and C-type synoptic pattern, respectively.

PSC	Temperature (°C)	Humidity (%)	Pressure (kpa)	Wind speed (m/s)
SW	11.79 (12.96)	75.33 (69.25)	1018.33 (1024.06)	2.13 (3.09)
NW	3.61 (6.34)	71.16 (62.78)	1027.53 (1031.53)	1.44 (2.45)
A	5.81 (7.52)	64.96 (60.38)	1026.63 (1028.66)	1.45 (2.27)
C	9.60 (13.08)	78.10 (71.40)	1011.48 (1014.24)	1.88 (3.11)

Table S4. The emission amount of $PM_{2.5}$ precursors over Central China calculated from SEEA (for the year 2017) and MEIC (for the years of 2013, 2014 and 2017) inventory (unit: 10^4 ton).

Category	SO_2	NO_X	NH_3	$PM_{2.5}$	CO	BC	OC	VOCs

SEEA (2017)	48.4	94.0	54.6	26.4	553.8	6.2	12.9	117.2
MEIC (2017)	52.0	70.4	57.5	35.2	629.2	6.8	11.7	116.4
MEIC (2013)	173.3	98.4	62.4	54.5	836.5	9.2	16.7	116.6
MEIC (2014)	97.0	80.0	61.1	46.8	744.2	8.3	15.3	116.4

Table 4 The reported concentrations of $PM_{2.5}$ and the three inorganic salts (sulfate, nitrate and ammonium, $\mu g/m^3$) in other cities.

References	Site	Time	$PM_{2.5}$	Sulfate	Nitrate	Ammonium
Cao et al., 2012	Beijing	01/03	115.6±46.6	20.0±4.2 (17.3%)	13.1±4.5 (11.3%)	9.4±4.1 (8.1%)
Cao et al., 2012	Qingdao	01/03	134.8±43.0	21.1±7.7 (15.7%)	19.3±9.2 (14.3%)	15.3±5.2 (11.4%)
Cao et al., 2012	Tianjin	01/03	203.1±76.2	32.5±15.1 (16.0%)	25.2±10.3 (12.4%)	22.2±9.8 (10.9%)
Cao et al., 2012	Xi'an	01/03	356.3±118.4	53.8±25.6 (15.1%)	29.0±10.0 (8.1%)	29.8±11.5 (8.4%)
Cao et al., 2012	Chongqing	01/03	316.6±101.2	60.9±19.6 (19.2%)	18.1±6.4 (5.7%)	28.8±8.9 (9.1%)
Cao et al., 2012	Hangzhou	01/03	177.3±59.5	33.4±16.7 (18.8%)	25.7±14.8 (14.5%)	19.1±10.7 (10.8%)
Cao et al., 2012	Shanghai	01/03	139.4±50.6	21.6±12.3 (15.5%)	17.5±8.7 (12.6%)	14.5±5.9 (10.4%)
Cao et al., 2012	Wuhan	01/03	172.3±67.0	31.4±15.6 (18.2%)	22.2±10.7 (12.9%)	18.4±10.2 (10.7%)
Zhang et al., 2011	Xi'an	03/06-03/07	194.1	35.6 (18.3%)	16.4 (8.4%)	11.4 (5.9%)
Huang et al., 2012	Xi'an	01/06-02/06	235.8±125.1	44.8±31.3 (19.0%)	20.5±14.2 (8.7%)	14.5±10.8 (6.1%)
Wang et al., 2020	Jinan	10/17	104±54	14.4±9.2 (13.8%)	33.4±23.2 (32.1%)	13.0±8.3 (12.5%)
Wang et al., 2020	Shijiazhuang	10/17	152±109	19.3±19.6 (12.7%)	42.8±41.1 (28.2%)	18.2±17.1 (12.0%)
Wang et al., 2020	Wuhan	12/17	117±33	13.6±3.2 (11.6%)	26.6±11.1 (22.7%)	13.1±3.8 (11.2%)
Wang et al., 2016a	Zhengzhou	01/11-02/11	297±160	48±36	31±19	21±16

				(16.2%)	(10.4%)	(7.1%)
Wang et al., 2016a	Zhengzhou	01/12-02/12	234±125	23±10 (9.8%)	22±9 (9.4%)	16±5 (6.8%)
Wang et al., 2016a	Zhengzhou	01/13-02/13	337±168	56±39 (16.6%)	39±20 (11.6%)	31±18 (9.2%)
Luo et al., 2018	Zibo	12/06-02/07	224.9±85.4	40.1±19.2 (17.9%)	18.1±9.0 (8.1%)	21.7±10.2 (9.7%)
Wang et al., 2016b	Shanghai	12/11, 12/12, 12/13	73.9±57.5	12.2±9.2 (16.5%)	14.6±12.2 (19.8%)	8.2±6.7 (11.1%)
Xu et al., 2019	Beijing	02/17-03/17	180.5	20.1 (11.1%)	45.6 (25.3%)	22.5 (12.5%)
Xu et al., 2019	Beijing	05/17-09/17	186.7	20.2 (10.8%)	32.4 (17.4%)	17.1 (9.2%)
Xu et al., 2019	Beijing	10/17-11/17	167.5	17.9 (10.7%)	44.5 (26.6%)	20.9 (12.5%)
Zheng et al., 2016	Beijing	03/10-05/10	65.2±65.1	11.1±10.1 (17.0%)	11.1±11.0 (17.0%)	6.8±6.7 (10.4%)
Zheng et al., 2016	Beijing	07/09-08/09	88.9±39.1	23.0±13.9 (25.9%)	16.2±11.8 (18.2%)	11.8±6.8 (13.3%)
Zheng et al., 2016	Beijing	12/09-02/10	84.0±66.6	8.1±8.3 (9.1%)	8.0±9.6 (9.0%)	5.9±7.1 (6.6%)
Zheng et al., 2016	Guangzhou	11/10	73.3±16.5	16.6±4.0 (22.6%)	5.7±3.8 (7.8%)	6.2±2.0 (8.5%)
Zheng et al., 2016	Shenzhen	12/09	64.6±24.7	20.6±3.5 (31.9%)	4.9±3.5 (7.6%)	4.6±1.0 (7.1%)
Zheng et al., 2016	Wuxi	04/10-05/10	82.1±27.0	12.8±3.8 (15.6%)	9.9±6.3 (12.1%)	7.0±2.0 (8.5%)
Zheng et al., 2016	Jinhua	10/11-11/11	81.9±26.2	18.3±6.7 (22.3%)	12.6±7.0 (15.4%)	10.4±4.1 (12.7%)
Liu et al., 2018	Chongqing	2012-2013	73.5±30.5	19.7±9.6 (26.8%)	6.5±6.2 (8.8%)	6.1±2.7 (8.3%)
Liu et al., 2018	Shanghai	2012-2013	68.4±20.3	13.6±6.4 (19.9%)	11.9±5.0 (17.4%)	5.8±2.1 (8.5%)
Liu et al., 2018	Beijing	2012-2013	71.7±36.0	11.9±8.2 (16.6%)	9.3±7.5 (13.0%)	5.3±2.7 (7.4%)

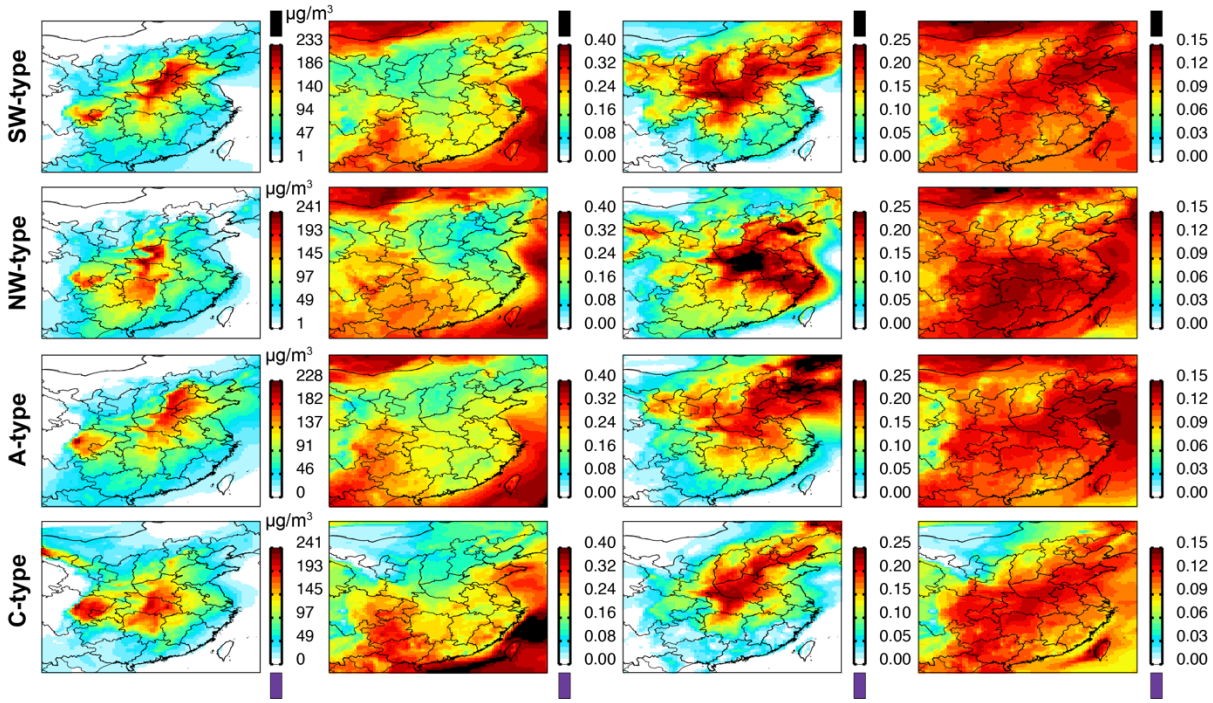

Figure S10 Spatial distribution of $PM_{2.5}$ concentrations and the fraction of each inorganic salt (sulfate: second column; nitrate: third column; ammonium: forth column) to $PM_{2.5}$ for these four typical heavy pollution processes simulated by GEOS-Chem control simulation.

Reference:

Cao, J.-J., Shen, Z.-X., Chow, J. C., Watson, J. G., Lee, S.-C., Tie, X.-X., Ho, K.-F., Wang, G.-H., and Han, Y.-M.: Winter and Summer PM2.5 Chemical Compositions in Fourteen Chinese Cities, Journal of the Air & Waste Management Association, 62, 1214-1226, 10.1080/10962247.2012.701193, 2012.

Huang, W., Cao, J., Tao, Y., Dai, L., Lu, S.-E., Hou, B., Wang, Z., and Zhu, T.: Seasonal Variation of Chemical Species Associated With Short-Term Mortality Effects of PM2.5 in Xi'an, a Central City in China, American Journal of Epidemiology, 175, 556-566, 10.1093/aje/kwr342, 2012.

Liu, Z., Gao, W., Yu, Y., Hu, B., Xin, J., Sun, Y., Wang, L., Wang, G., Bi, X., Zhang, G., Xu, H., Cong, Z., He, J., Xu, J., and Wang, Y.: Characteristics of PM2.5 mass concentrations and chemical species in urban and background areas of China: emerging results from the CARE-China network, Atmospheric Chemistry and Physics, 18, 8849-8871, 10.5194/acp-18-8849-2018, 2018.

Luo, Y., Zhou, X., Zhang, J., Xiao, Y., Wang, Z., Zhou, Y., and Wang, W.: PM2.5 pollution in a petrochemical industry city of northern China: Seasonal variation and source apportionment, Atmospheric Research, 212, 285-295, 10.1016/j.atmosres.2018.05.029, 2018.

Wang, H. L., Qiao, L. P., Lou, S. R., Zhou, M., Ding, A. J., Huang, H. Y., Chen, J. M., Wang, Q., Tao, S., Chen, C. H., Li, L., and Huang, C.: Chemical composition of PM2.5 and meteorological impact among three years in urban Shanghai, China, Journal of Cleaner Production, 112, 1302-1311, 10.1016/j.jclepro.2015.04.099, 2016a.

Wang, J., Li, X., Zhang, W., Jiang, N., Zhang, R., and Tang, X.: Secondary PM2.5 in Zhengzhou, China: Chemical Species Based on Three Years of Observations, Aerosol and Air Quality Research, 16, 91-104, 10.4209/aaqr.2015.01.0007, 2016b.

Wang, Q., Fang, J., Shi, W., and Dong, X.: Distribution characteristics and policy-related improvements of PM2.5 and its components in six Chinese cities, Environmental Pollution, 266, 10.1016/j.envpol.2020.115299, 2020.

Xu, Q., Wang, S., Jiang, J., Bhattarai, N., Li, X., Chang, X., Qiu, X., Zheng, M., Hua, Y., and Hao, J.: Nitrate dominates the chemical composition of PM2.5 during haze event in Beijing, China, Science of the Total Environment, 689, 1293-1303, 10.1016/j.scitotenv.2019.06.294, 2019.

Zhang, T., Cao, J. J., Tie, X. X., Shen, Z. X., Liu, S. X., Ding, H., Han, Y. M., Wang, G. H., Ho, K. F., Qiang, J., and Li, W. T.: Water-soluble ions in atmospheric aerosols measured in Xi'an, China: Seasonal variations and sources, Atmospheric Research, 102, 110-119, 10.1016/j.atmosres.2011.06.014, 2011.

Zheng, J., Hu, M., Peng, J., Wu, Z., Kumar, P., Li, M., Wang, Y., and Guo, S.: Spatial distributions and chemical properties of PM2.5 based on 21 field campaigns at 17 sites in China, Chemosphere, 159, 480-487, 10.1016/j.chemosphere.2016.06.032, 2016.

Minor comments:

Line 101-103: There must be many studies targeted the mitigation of PM2.5 at a regional scale (Ding et al., 2019; Zhang et al., 2019, Xing et al., 2018, 2019; Fu et al., 2017; etc.). Please rephrase this sentence.

We have rephrased this sentence: "Although there are many studies targeted $PM_{2.5}$ mitigations at a regional scale (Ding et al., 2019; Zhang et al., 2019, Xing et al., 2018, 2019; Fu et al., 2017; etc.), their results can not be directly applied to reduce winter $PM_{2.5}$ pollution under various synoptic controls."

Line 148-150: It is very confusing. The circulation classification is based on the meteorological data from November 2013 to February 2014, which is also the simulation episode. Why did you use the hourly PM2.5 data from 2013-2018?

We used the hourly $PM_{2.5}$ from November 2013 to December 2018 to screen the pollution days (daily mean $PM_{2.5}$ larger than 150 $\mu g/m^3$) and applied the daily mean sea level pressure between 2013 and 2018 from the NCEP/NCAR FNL Operational Global Analysis data to conduct the circulation classification. The meteorological observations at Jingzhou from November 2013 to February 2014 are used to analyze the meteorological characteristics during the period four severe particle pollution events occurred in succession over Central China. We have revised the Sect. 2.1:

"Hourly mass concentrations of $PM_{2.5}$ at Jingzhou (112.18°E, 30.33°N, 33.7 m) from November 2013 to December 2018 are obtained from Hubei Environmental Monitoring Central Station (http://sthjt.hubei.gov.cn/). We screen the pollution days with daily mean $PM_{2.5}$ concentrations larger than 150 $\mu g/m^3$ for circulation classification.

We use the daily mean sea level pressure (SLP) between 2013 and 2018 from the National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) Final (FNL) Operational Global Analysis data (horizontal resolution: 1° × 1°; temporal resolution: 6 hours; https://rda.ucar.edu/datasets/ds083.3/) to conduct the classification of Lamb-Jenkension circulation types.

The meteorological data of surface observations at Jingzhou, including ambient temperature, relative humidity, wind speed, wind direction and atmospheric pressure, are obtained from Hubei Meteorological Information and Technology Support Center (http://hb.cma.gov.cn/qxfw/index.html). The data from November 2013 to February 2014 are used to analyze the meteorological characteristics during the period four severe particle pollution events occurred in succession over Central China (Fig. S1)."

Line 195: Did you do nested runs or just one domain covering China? Please make this clear.

We have specified the model setups in the revised sentences: "The nested model, covering China (70°E-140°E, 15°S-55°N), is run with a horizontal resolution of 0.25° latitude × 0.3125° longitude and 72 vertical layers. The boundary condition of nested model is provided by the GEOS-Chem global model with a horizontal resolution of 2° latitude × 2.5° longitude (Fig. S3). Both global and nested simulations, driven by the GEOS-FP assimilated meteorological data, include detailed tropospheric Ozone-NO_x-VOCs-HO_x-aerosol chemistry."

Line 205: The SEEA inventory was developed for the year 2017. Did you use it directly without projection to the simulation episode? If you adjusted this inventory, what are the factors applied for the PM2.5 precursors and how did you obtain those data?

Yes, we have used the SEEA inventory of the year 2017 directly without projection to the simulation episode. The uncertainty discussion has been listed in Sect. 3.3: "Anthropogenic emissions for $PM_{2.5}$ precursors used here are for the year 2017 over Central China from SEEA inventory (Table S4). From 2013 to 2017, anthropogenic NO_x, SO_2, and primary $PM_{2.5}$ emissions in Central China have declined substantially (Table S4), due to implementation of stringent emission control measures for the 12^{th}-13^{th} Five-Year Plans (Zheng et al., 2018). The anthropogenic emissions biases may affect our simulations and $PM_{2.5}$ attribution results to some extent."

Line 215-217: Have you compared the modeled sulfate with observations, at least in Jingzhou? How about the model performances of the other components of PM2.5?

We have no observations of the chemical compositions of $PM_{2.5}$. In order to examine the model performances in the $PM_{2.5}$ chemical compositions, we have added Table 4 to review the reported concentrations of $PM_{2.5}$ and the three inorganic salts (sulfate, nitrate and ammonium) in other cities. The contributions of sulfate, nitrate and ammonium are 9.1%-31.9%, 5.7%-32.1% and 5.9%-13.3%, respectively. In the CON simulation, the fractions of each inorganic salt to $PM_{2.5}$ for these four typical heavy pollution processes are shown in revised Fig. S10, which are comparable to the previous observed results (Table 4). Please see details in the response of major comment#4.

Line 305: Again, I am confused about the emissions used in the CON case. You listed too many options for the anthropogenic source in Table S2. What inventories were EXACTLY selected for the CON case? Did you do a global/regional nested run? Please explain the choices of emissions in a separate column in the table.

We do a nested simulation, covering China (70°E-140°E, 15°S-55°N) with a horizontal resolution of 0.25° latitude × 0.3125° longitude. The boundary condition of nested model is provided by the GEOS-Chem global model with a horizontal resolution of 2° latitude × 2.5° longitude (Fig. S3). The emission inventories for each domain are shown in the revised Table S1 and Table S2. Please see details in the response of major comment#2.

Line 310: Please compare the meteorological field used in the model with observations to confirm that statement. Also, there are no perfect mechanisms, inventories, or parameterization of the model with no doubt. I suggest using "uncertainties".

We thank the referee for this comment. In order to explain the causes of the model discrepancy, we have added Table S3 to show the observed (modeled) meteorological conditions averaged over these four pollution episodes controlled by SW-type, NW-type, A-type and C-type synoptic pattern, respectively. There is an overestimate in temperature and wind speed and an underestimate in humidity, which can partly contribute to the underestimation of modeled $PM_{2.5}$ concentrations. In addition, anthropogenic emissions for $PM_{2.5}$ precursors used here are for the year 2017 over Central China from SEEA inventory (Table S4). From 2013 to 2017, anthropogenic NO_x, SO_2, and primary $PM_{2.5}$ emissions in Central China have declined substantially (Table S4), due to implementation of stringent emission control measures for the 12^{th}-13^{th} Five-Year Plans (Zheng et al., 2018). The anthropogenic emissions biases may affect our simulations and $PM_{2.5}$ attribution results to some extent. Additionally, the underestimation is on a national scale when compared with the MEE observations, with a bias of -29.3 $\mu g/m^3$, -18.7 $\mu g/m^3$, -39.0 $\mu g/m^3$ and -21.4 $\mu g/m^3$ on average for SW-type, NW-type, A-type and C-type synoptic pattern, respectively (Fig. 6). The national negative biases may be also attributed to insufficient resolution of the model (Yan et al., 2014) and imperfect chemical mechanisms (Yan et al., 2019). Please see details in the response of major comment#4.

Line 323-324: A comparison of the modeled fractions of the inorganic salts to observations, or reported values from other literature if no measurements are available.

We have no observations of the chemical compositions of $PM_{2.5}$. In order to examine the model

performances in the $PM_{2.5}$ chemical compositions, we have added Table 4 to review the reported concentrations of $PM_{2.5}$ and the three inorganic salts (sulfate, nitrate and ammonium) in other cities. The contributions of sulfate, nitrate and ammonium are 9.1%-31.9%, 5.7%-32.1% and 5.9%-13.3%, respectively. In the CON simulation, the fractions of each inorganic salt to $PM_{2.5}$ for these four typical heavy pollution processes are shown in revised Fig. S10, which are comparable to the previous observed results (Table 4). Please see details in the response of major comment#4.

Line 324: "As shown in Table 3, ..."

Modified.

Line 358: How was this calculated? Please explain it.

We have added the explanation in the revised sentence: "In addition, the contributions from transboundary transport from non-Jingzhou Central China is simulated to be 12.0% by comparing the results of XJ0 and XCC0."

Line 415-417: How about the contributions of transported pollutants to the chemical composition of PM2.5 under the four PSCs?

We have discussed in the revised Sect. 3.4. During the pollution episodes of transmission-pollution characteristics (SW/NW-type), the contribution of transported pollutants to the chemical composition of $PM_{2.5}$ is significant. For the SW-type synoptic controlled pollution event, the transport of air pollutants from the south leads to the smallest proportion of the three inorganic salts (45.7%) in Jingzhou among the four pollution episodes (50.3%-55.5% for other three episodes), because the emissions of SO_2, NO_2 and NH_3 in the south (especially in Guangxi and Guizhou province) are smaller than those in Central China (Li et al., 2017a). However, during the NW-type synoptic controlled pollution episode, due to the transport contribution of pollutants from northern China (with much higher anthropogenic emissions of SO_2, NO_2 and NH_3) (Li et al., 2017a), the total proportion of the three inorganic salts is the highest (55.5%). For the other two types (A/C-type) synoptic controlled pollutions, local emission sources dominate the contributions and the contributions of transported pollutants to the chemical composition of $PM_{2.5}$ are small.

Line 424: The base year of emission reduction is 2015 for the 13th Five-year plan, which is quite different from your inventory. How effective is the designed reduction ratio of the anthropogenic emissions in this study?

Although the base year of emission reduction is 2015 for the 13^{th} Five-year plan, it does not affect to use the simulation results of emission scenarios (with the reduction ratio of 20% applied to the simulated year 2013/2014) to explore the emission reduction effect of specific haze pollution events. We have added this illustration in the revised Sect. 3.5.

Line 425 and 428-429: Please explain these abbreviations in the text as well.

We have revised these sentences as: "The differences in model results between CON (control simulation) and JSN/JSNN/JALL (emissions of $(SO_2+NO_x)/(SO_2+NO_x+NH_3)$/all pollution sources at Jingzhou are reduced by 20%) represent the environmental benefits caused by different local emission reduction scenarios. The potential $PM_{2.5}$ mitigations by joint prevention and control in different regions are calculated by sensitivity experiments of CCALL (emissions of all pollution sources over Central China are reduced by 20%), CNALL (over Central China and NCP region), CPALL (over Central China and PRD region) and TALL (over Central China, NCP, YRD, PRD and SCB regions)."

Line 437: I think an evaluation of the model performance in ammonium and/or ammonia is desired to confirm that.

We thank the referee for this comment. We have no observations of the chemical compositions of $PM_{2.5}$. Thus we have removed this statement in the revised text.

Figure 6, 8, 9, 10: I suggest to show the fraction of each inorganic salt to PM2.5 rather than their total mass.

We have shown the fraction of each inorganic salt to $PM_{2.5}$ in the revised Fig. S10.

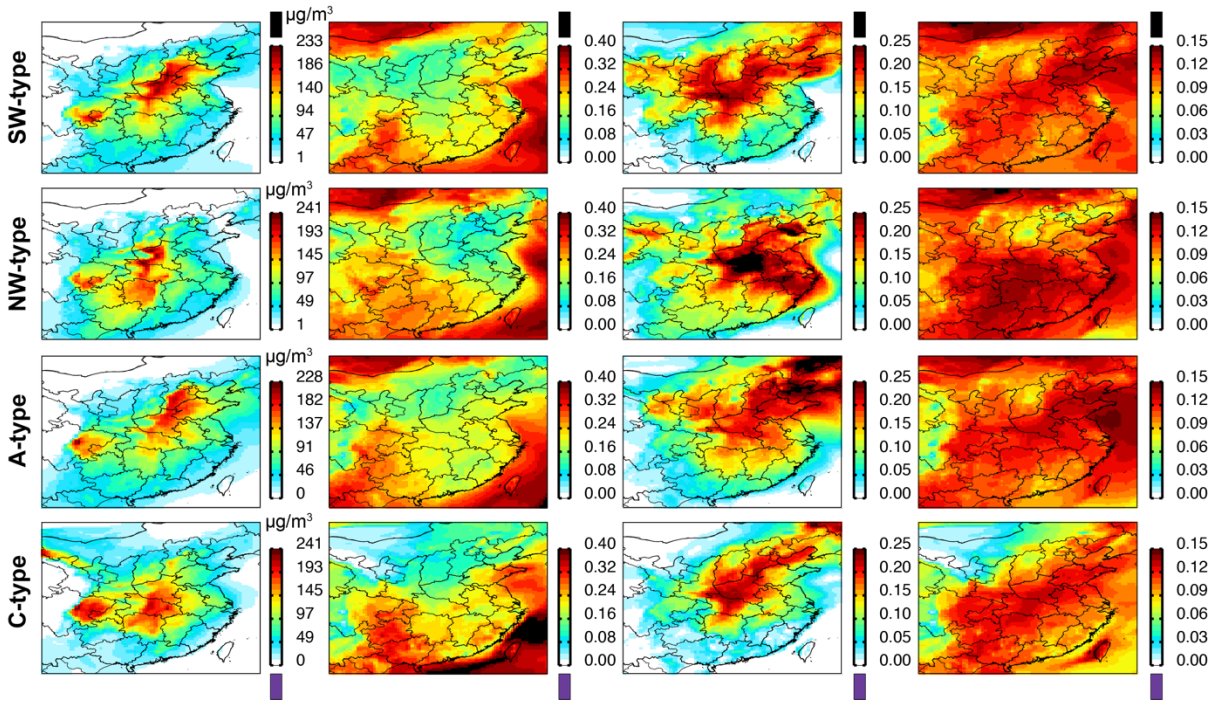

Figure S10 Spatial distribution of $PM_{2.5}$ concentrations and the fraction of each inorganic salt (sulfate: second column; nitrate: third column; ammonium: forth column) to $PM_{2.5}$ for these four typical heavy pollution processes simulated by GEOS-Chem control simulation.

Figure 11. It should be "TALL" in NW and C.

Modified.

References:

Wenyuan Chang and Jianqiong Zhan, The association of weather patterns with haze episodes: Recognition by $PM_{2.5}$ oriented circulation classification applied in Xiamen, Southeastern China, Atmospheric Research, 197, 425-436, 2017.

Huibin Dai, Jia Zhu, Hong Liao, Jiandong Li, Muxue Liang, Yang Yang, Xu Yue, Co-occurrence of ozone and $PM_{2.5}$ pollution in the Yangtze River Delta over 2013–2019: Spatiotemporal distribution and meteorological conditions, Atmospheric Research, 249, 105363, 2021.

Qiang Zhang, Yixuan Zheng, Dan Tong, et al., Drivers of improved $PM_{2.5}$ air quality in China from 2013 to 2017, Proceedings of the National Academy of Sciences, 116 (49) 24463-24469, 2019.

Aijun Ding, Xin Huang, Wei Nie, et al., Significant reduction of $PM_{2.5}$ in eastern China due to regional-scale emission control: evidence from SORPES in 2011–2018, Atmospheric Chemistry and Physics, 19, 11791– 11801, 2019.

Xing, J., Ding, D., Wang, S., Dong, Z., Kelly, J. T., Jang, C., ... & Hao, J. Development and application of observable response indicators for design of an effective ozone and fine-particle pollution control strategy in China. Atmospheric Chemistry & Physics, 19(21), 2019.

Xing, J., Ding, D., Wang, S., Zhao, B., Jang, C., Wu, W., ... & Hao, J. Quantification of the enhanced effectiveness of NOx control from simultaneous reductions of VOC and NH_3 for reducing air pollution in the Beijing–Tianjin–Hebei region, China. Atmospheric Chemistry and Physics, 18(11), 7799-7814, 2018.

Fu, X., Wang, S.,Xing, J., Zhang, X., Wang, T., & Hao, J. Increasing ammonia concentrations reduce the effectiveness of particle pollution control achieved via SO_2 and NO_X emissions reduction in east China. Environmental Science & Technology Letters, 4(6), 221-227, 2017.