Response to comments #1

Response: We thank the reviewer's helpful and constructive comments. We have made several modifications and implemented the suggestions as needed. We describe a few major changes, followed by our response to individual comments.

RC1 comments:

The manuscript by Zhang and colleagues models the change in ozone and $PM_{2.5}$ and related health impacts in China and downwind countries due to emission changes in China after the implementation of APPCAP. Overall, most of the results presented in this paper on decrease in $PM_{2.5}$ in China post APPCAP is not new and has been established in multiple studies involving models/measurements. The new aspect is assessing its impact in details on $PM_{2.5}$ and ozone exposure and related mortality burden in downwind regions, though the TF-HTAP initiative partly addresses this.

Response: We appreciate the reviewer's efforts in providing constructive comments for our paper. Though we made several significant changes based on the reviewer's comments below, we disagree with the reviewer's opinion that our study was not innovative enough. First, our study's time frame covers 2010 to 2017, which is before and after implementation of APPCAP in China in 2013, unlike the other studies (e.g., Zheng Y. et al., 2017; Huang et al., 2018; Zhang et al., 2019; Ding et al., 2019a, b; Li et al., 2019 and so on) which only emphasized the air quality and health improvements after implementation of APPCAP in 2013. Meanwhile, in our study, we explored how the emission changes in China, including both emission increases and decreases, have influences on both domestic and downwind regions' air quality and human health, while the other studies mentioned above only discussed the air quality changes in China. Second, the studies in the TF-HTAP (Liang et al., 2018, as pointed out by the reviewer) investigated the changes in air quality and human health from hypothetical 20 % anthropogenic emission reductions from East Asia (including China, Japan, Korea), while we used the up-to-date high-resolution bottom-up emission developed by our coauthors in China from 2010 to 2017, with emission changes of −62 % for SO_2, −17 % for NO_x, +11 % for nonmethane volatile organic compounds (NMVOCs), +1 % for NH_3, −27 % for CO, −35 % for $PM_{2.5}$, −27 % for BC and −35 % for OC (Zheng et al., 2018). In conclusion, our study is innovated in studying both the domestic and downwind regions' air quality changes from emission changes in China from 2010 to 2017, which was also acknowledged by reviewer 2.

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Ding, D., Xing, J., Wang, S., Liu, K. and Hao, J.: Estimated Contributions of Emissions Controls, Meteorological Factors, Population Growth, and Changes in Baseline Mortality to Reductions in Ambient $PM_{2.5}$ and $PM_{2.5}$-Related Mortality in China, 2013-2017, Environ. Health Perspect., 127(6), 67009, doi:10.1289/EHP4157, 2019a.

Ding, D., Xing, J., Wang, S., Chang, X. and Hao, J.: Impacts of emissions and meteorological changes on China's ozone pollution in the warm seasons of 2013 and 2017, Front. Environ. Sci. Eng., 13(5), 1–9, doi:10.1007/s11783-019-1160-1, 2019b.

Huang, J., Pan, X., Guo, X. and Li, G.: Health impact of China's Air Pollution Prevention and Control Action Plan: an analysis of national air quality monitoring and mortality data, Lancet Planet. Heal., 2(7), e313–e323, doi:10.1016/S2542-5196(18)30141-4, 2018.

Li, K., Jacob, D. J., Liao, H., Shen, L., Zhang, Q. and Bates, K. H.: Anthropogenic drivers of 2013–2017 trends in summer surface ozone in China, Proc. Natl. Acad. Sci. U. S. A., 116(2), 422–427, doi:10.1073/pnas.1812168116, 2019.

Liang, C.-K., West, J. J., Silva, R. A., Bian, H., Chin, M., Davila, Y., Dentener, F. J., Emmons, L., Flemming, J., Folberth, G., Henze, D., Im, U., Jonson, J. E., Keating, T. J., Kucsera, T., Lenzen, A., Lin, M., Lund, M. T., Pan, X., Park, R. J., Pierce, R. B., Sekiya, T., Sudo, K., and Takemura, T.: HTAP2 multi-model estimates of premature human mortality due to intercontinental transport of air pollution and emission sectors, Atmos. Chem. Phys., 18, 10497–10520, https://doi.org/10.5194/acp-18-10497-2018, 2018.

Zhang, Q., Zheng, Y., Tong, D., Shao, M., Wang, S., Zhang, Y., Xu, X., Wang, J., He, H., Liu, W., Ding, Y., Lei, Y., Li, J., Wang, Z., Zhang, X., Wang, Y., Cheng, J., Liu, Y., Shi, Q., Yan, L., Geng, G., Hong, C., Li, M., Liu, F., Zheng, B., Cao, J., Ding, A., Gao, J., Fu, Q., Huo, J., Liu, B., Liu, Z., Yang, F., He, K. and Hao, J.: Drivers of improved $PM_{2.5}$ air quality in China from 2013 to 2017, Proc. Natl. Acad. Sci. U. S. A., 116(49), 24463–24469, doi:10.1073/pnas.1907956116, 2019.

Zheng, Y., Xue, T., Zhang, Q., Geng, G., Tong, D., Li, X. and He, K.: Air quality improvements and health benefits from China's clean air action since 2013, Environ. Res. Lett., 12(114020), doi:https://doi.org/10.1088/1748-9326/aa8a32, 2017.

Zheng, B., Tong, D., Li, M., Liu, F., Hong, C., Geng, G., Li, H., Li, X., Peng, L., Qi, J., Yan, L., Zhang, Y., Zhao, H., Zheng, Y., He, K. and Zhang, Q.: Trends in China's anthropogenic emissions since 2010 as the cosnsequence of clean air actions, Atmos. Chem. Phys., 18(19), 14095–14111, doi:10.5194/acp-18-14095-2018, 2018b.

I list a few major issues which the authors may want to address-

- It might be interesting to check if there are any seasonal differences in change in $PM_{2.5}$ and ozone in China and also in downwind regions after the implementation of APPCAP.

Response: We thank the reviewer's suggestion. We now add two plots showing seasonal air quality changes for both Population-weighted $PM_{2.5}$ and MDA8 O_3 in China, Japan, South Korea and U.S. (Figs. S6 & S7 in the supporting). From the plots below, we conclude that for both China and downwind regions, the surface $PM_{2.5}$ changes due to emission changes in China usually peak in the fall and winter (Fig. S7). For ozone, the emission changes from 2010 to 2013 exacerbate summer ozone pollution in China, while alleviate ozone pollution in the other three regions (Fig. S8). After 2013, the emission decreases in China exacerbate the ozone pollution for all the seasons, especially in winter. For the downwind regions, the season with peak ozone changes also varies.

We now add the discussions of the seasonal air quality changes in the following paragraphs:
Line 201: "The surface $PM_{2.5}$ changes in China due to emission changes usually peak in the fall and winter (Fig. S7a)."

Line 213-215: "For ozone, the emission changes from 2010 to 2013 exacerbate summer ozone pollution in China, but alleviate ozone pollution in the other three regions (Fig. S8a). After 2013, the emission decreases in China exacerbate the ozone pollution for all the seasons, especially in winter.".

Line 235-236:" The influences are largest in spring than the other seasons for all the downwind regions (Fig. S7b-d)."

Line 239-240:" For the downwind regions, the season with peak ozone changes also varies (Fig. S8b-d)."

Fig. S7. Seasonal population-weighted $PM_{2.5}$ changes in China (a), Japan (b), South Korea (c), and U.S. (d) from 2010 to 2017 (CEDS_MEIC – CEDS_MEIC_ChinaFix).

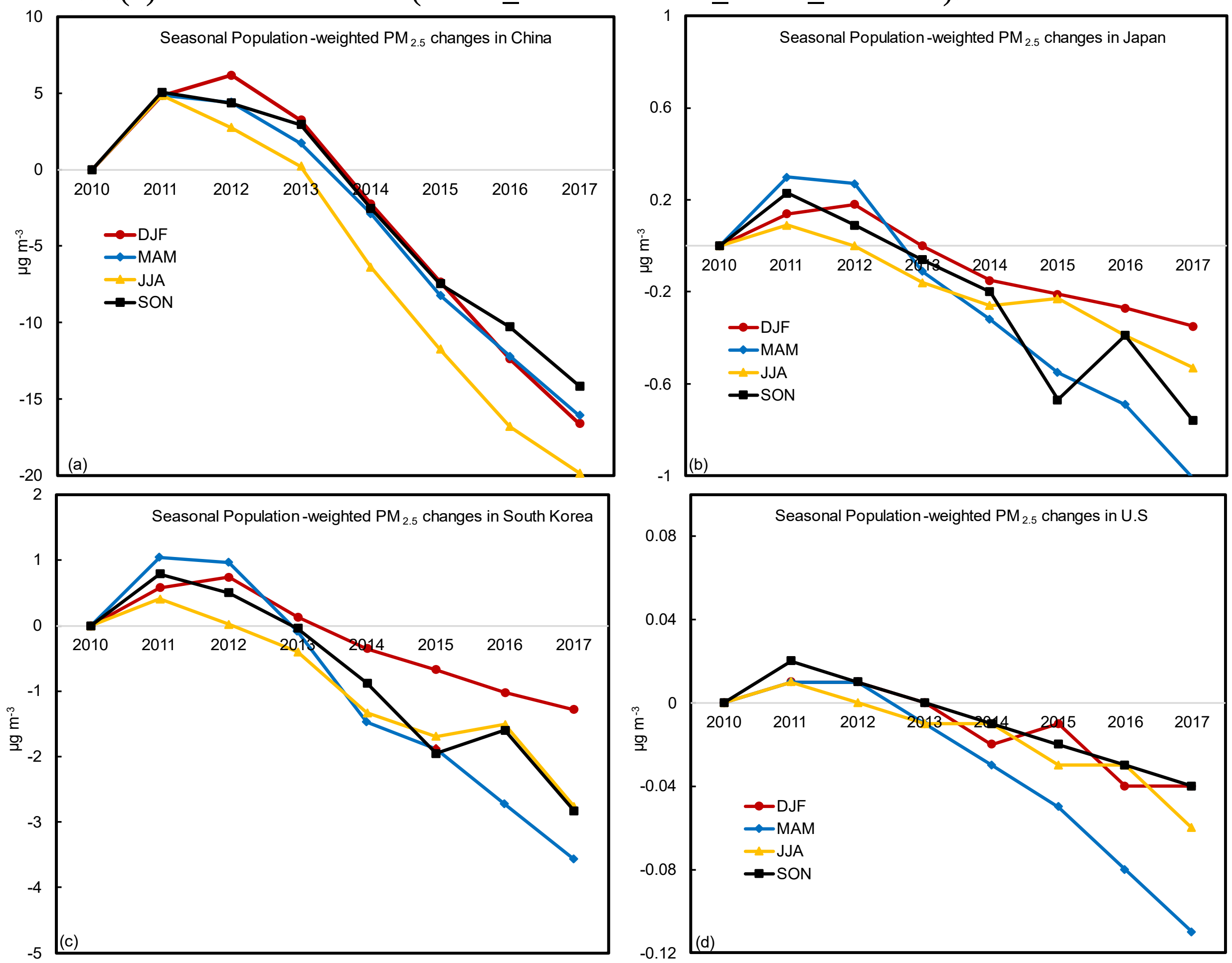
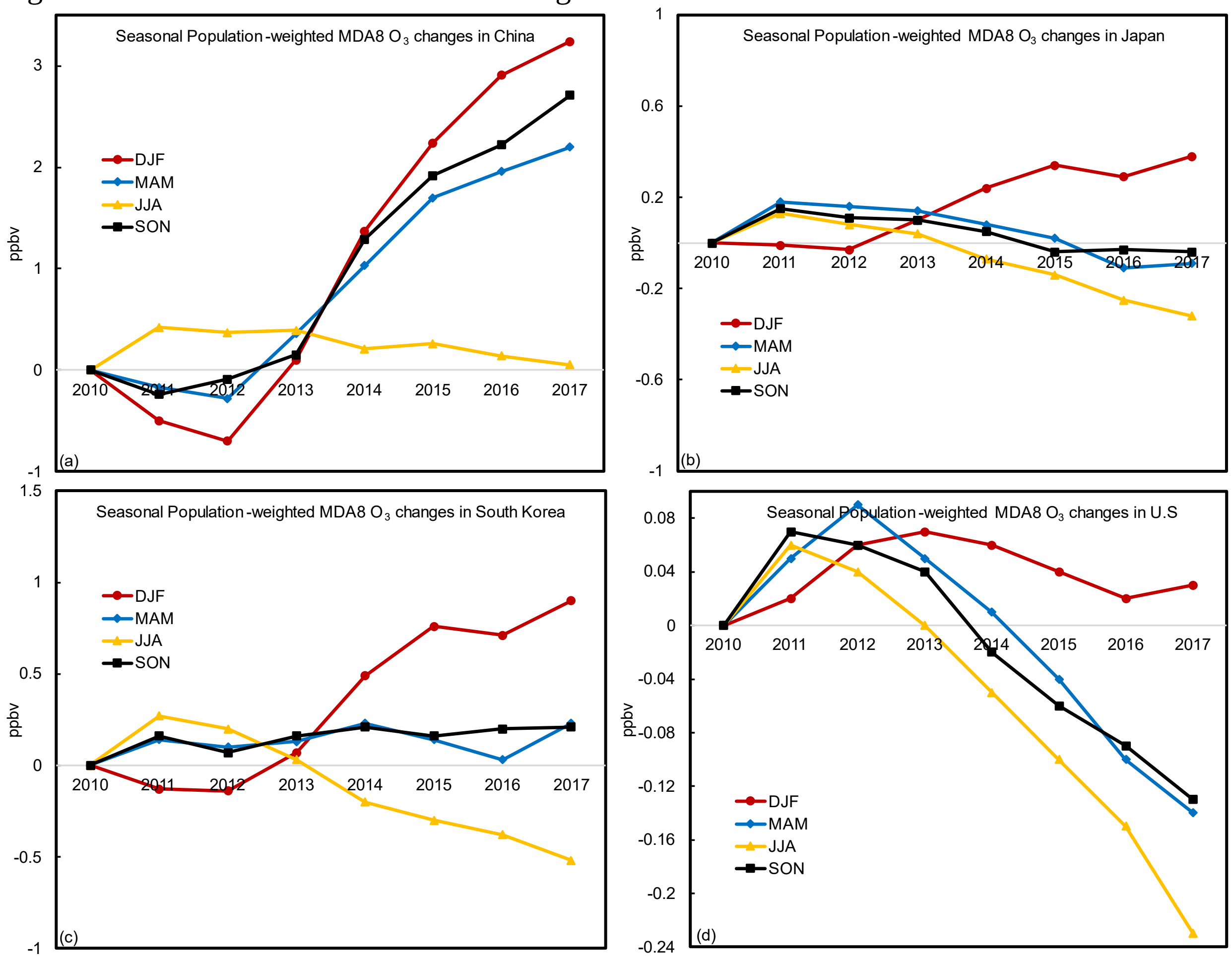


Fig. S8. Same as S7 but for MDA8 O3 changes.



- China has a distinct east to west gradient in air pollution exposure. Rather than speculating this east to west gradient in changes in $PM_{2.5}$ after the APPCAP, the authors may consider representing this information (on changes in population weighted $PM_{2.5}$, ozone and averted premature death) by provinces in China, which might be more policy relevant. The authors may also plan to inspect changes in emissions in which provinces led to maximum benefit in terms of averted death in a downwind country, if feasible. They might also plan to estimate the averted mortality/exposure in a downwind country by province. Eg- In USA the maximum benefit is expected to be realized in the western states of CA, OR and WA.

  Response: We now add a table S1-S4 in the supporting materials, listing the province-level air quality changes as well as mortality burden changes in China from 2011 to 2017. We also add the discussions of province-level results in the following texts:

  Line 203-204: "Spatially, we see that significant $PM_{2.5}$ changes (increases before 2013 and decreases thereafter) occur in eastern China (Fig. 2), which was the focus region for China in the APPCAP (Ding et al., 2019a,b)."

Line 215-216: "The spatial pattern of ozone trends mainly featured increases in the Beijing–Tianjin–Hebei and Yangtze-River-Delta regions, and slightly decreases in the south (Fig. 3; Fig. S5; Table S2)."

The mortality burden changes in the U.S. are small (from 5 to 400 deaths/yr in Tables S4-S5), and so we will not include a state-level analysis for U.S.

Table S1. The annual $PM_{2.5}$ changes at China provinces from 2011 to 2017 (CEDS_MEIC – CEDS_MEIC_ChinaFix; unit of μg m^{-3}).

Provinces	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
Anhui	7.32	5.64	2.19	-4.24	-12.14	-17.56	-22.84
Beijing	3.99	6.19	5.66	3	-1.87	-5.65	-9.07
Chongqing	4.11	2.74	0.92	-6.32	-11.63	-16.62	-21.13
Fujian	1.89	2.66	0.9	-3.5	-4.9	-7.44	-9.02
Gansu	0.92	0.77	0.35	-1.75	-3.26	-4.33	-5.76
Guangdong	4.18	3.66	1.84	-2.32	-4.76	-7.7	-10.24
Guangxi	4.73	4.85	2.73	-1.46	-4.7	-8.88	-11.24
Guizhou	3.37	4.21	5.91	3.06	-0.18	-3.85	-6.54
Hainan	1.48	1.77	2.1	-1.07	-1.77	-4.24	-6.54
Hebei	5.85	7.04	5.61	0.39	-5.85	-10.81	-15.4
Heilongjiang	1.96	2.1	0.57	-0.49	-2.02	-3.29	-3.83
Henan	9.77	6.09	0.45	-9.28	-23.24	-30.96	-37.58
Hubei	6.82	4.43	0.5	-9.34	-16.31	-20.76	-25.82
Hunan	4.67	4.33	3.1	-3.4	-5.8	-10.65	-14.67
Jiangsu	6.54	4.25	-1.26	-4.14	-11.08	-15.51	-19.87
Jiangxi	2.66	2.53	1.66	-3.04	-4.73	-9.4	-12.97
Jilin	2.65	3.39	1.73	-1.54	-4.13	-5.79	-6.48
Liaoning	2.95	1.71	-0.88	-4.06	-6.95	-9.31	-10.58
Nei Mongol	1.32	0.14	-0.58	-1.12	-1.91	-2.77	-3.36
Ningxia Hui	2.36	1.85	1.06	-2.3	-4.94	-6.89	-9.57
Qinghai	0.18	0.15	-0.05	-0.53	-0.84	-1.14	-1.67
Shaanxi	4.08	4.73	3.25	-4.28	-10.6	-13.99	-17.33
Shandong	6.94	6.74	1.04	-6.6	-13.91	-19.62	-23.98
Shanghai	2.36	1.13	-1.02	-2.67	-4.88	-5.74	-8.1
Shanxi	4.83	3.71	1.9	-2.5	-8.13	-12.32	-16.84
Sichuan	1.47	2.14	1.64	-2.76	-6.16	-9.48	-12.16
Tianjin	4.97	5.93	6.32	2.61	-2.36	-5.96	-10.18
Xinjiang Uygur	0.53	1.66	2.11	1.92	1.65	1.3	1.06
Xizang	0.03	0.06	0.03	-0.02	0.01	-0.01	-0.04
Yunnan	0.75	1.25	2.12	1.14	-0.14	-1.91	-2.7
Zhejiang	2.65	1.79	0.4	-4.49	-7.6	-9.21	-12.17

Table S2. The same as Table S1 but for MDA8 ozone (unit of ppbv).

Provinces	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
Anhui	-0.34	-0.41	-0.08	0.6	1.34	1.63	1.83
Beijing	-0.92	-0.75	0.24	3.16	5.27	6.15	6.43
Chongqing	0.53	0.48	0.84	1.03	0.96	1.2	1.73

Fujian	0.26	0.28	0.26	0.28	0.28	0.2	0.2
Gansu	0.47	0.58	0.71	0.89	0.85	0.85	0.73
Guangdong	0.1	0.14	0.47	0.33	0.12	0.08	-0.01
Guangxi	0.42	0.53	0.73	0.32	0.19	-0.11	-0.15
Guizhou	0.33	0.11	0.22	0.3	0.17	0.1	0.24
Hainan	0.34	0.48	0.35	0.18	0.15	0.02	-0.13
Hebei	-0.72	-0.81	-0.22	2.22	4.09	4.83	5.07
Heilongjiang	0.05	-0.14	0	-0.3	0	0.01	0.09
Henan	-0.39	0.06	0.66	2.08	3.57	3.96	4.37
Hubei	0.03	0.32	1.1	2.09	2.38	2.49	2.92
Hunan	0.32	0.38	0.51	0.56	0.4	0.44	0.69
Jiangsu	-0.7	-1.16	0.19	1.3	2.26	2.65	3.04
Jiangxi	0.09	0.49	0.43	0.72	0.77	0.82	0.97
Jilin	0	-0.17	0	0.34	0.54	0.54	0.69
Liaoning	-0.07	-0.16	0.1	0.69	0.97	1.05	1.27
Nei Mongol	-0.17	-0.04	0.07	0.44	0.54	0.48	0.5
Ningxia Hui	0.16	0.1	0.59	1.5	2.23	2.22	2.11
Qinghai	0.41	0.6	0.49	0.14	-0.01	-0.2	-0.52
Shaanxi	-0.04	-0.15	0.4	1.84	2.61	2.95	3.38
Shandong	-0.2	-0.9	0.03	0.7	1.75	2.51	3.16
Shanghai	-0.37	-0.28	0.59	1.53	2.17	2.36	2.57
Shanxi	-0.89	-0.78	-0.41	2.36	3.96	4.73	5.08
Sichuan	0.5	0.66	0.74	0.48	0.34	0.41	0.58
Tianjin	-1.32	-1.12	0.59	2.42	5.81	7.11	7.25
Xinjiang Uygur	0.16	0.32	-0.02	-0.08	-0.11	-0.06	0.01
Xizang	0.15	0.26	0.19	0	0.02	-0.09	-0.23
Yunnan	0.26	0.31	0.23	0.18	0.13	0.1	0.09
Zhejiang	-0.13	-0.22	0.15	0.93	1.41	1.58	1.75

Table S3. The annual $PM_{2.5}$ mortality burden changes at China provinces from 2011 to 2017 (CEDS_MEIC – CEDS_MEIC_ChinaFix; unit of deaths yr^{-1}).

Provinces	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
Anhui	1261	1072	463	-831	-2490	-3997	-4944
Beijing	341	508	450	180	-196	-503	-840
Chongqing	505	390	136	-594	-1217	-2007	-2545
Fujian	581	689	234	-1277	-1742	-2761	-3237
Gansu	371	370	94	-587	-1133	-1602	-2121
Guangdong	2652	2626	1245	-1437	-3529	-5962	-7481
Guangxi	1466	1741	830	-756	-1950	-3712	-4607
Guizhou	721	1055	1285	686	27	-854	-1493
Hainan	83	117	123	-65	-115	-283	-441
Hebei	1270	1611	1237	-34	-1397	-2448	-3787
Heilongjiang	738	914	297	-17	-540	-1052	-1362
Henan	1988	1408	274	-1872	-4703	-6820	-8645
Hubei	1473	1190	452	-1836	-3448	-5040	-6146
Hunan	1319	1365	979	-1017	-1785	-3557	-4791
Jiangsu	1488	1058	-452	-1431	-3485	-5038	-6286
Jiangxi	719	788	532	-976	-1579	-3334	-4269
Jilin	491	671	338	-244	-714	-1105	-1314
Liaoning	568	263	-246	-798	-1360	-1936	-2282
Nei Mongol	500	12	-248	-431	-753	-1170	-1460
Ningxia Hui	134	76	0	-117	-231	-364	-507
Qinghai	70	50	-14	-157	-267	-373	-476
Shaanxi	895	1161	584	-731	-1753	-2462	-3261
Shandong	1499	1575	159	-1831	-3850	-5434	-6833
Shanghai	251	134	-148	-417	-753	-960	-1227
Shanxi	650	537	204	-353	-1041	-1641	-2351
Sichuan	973	1385	841	-1707	-3711	-6001	-7524
Tianjin	202	249	240	92	-92	-231	-409
Xinjiang Uygur	331	929	1200	1170	1082	913	778
Xizang	8	11	9	-4	11	5	-3
Yunnan	421	741	1013	544	-100	-977	-1542
Zhejiang	725	597	112	-1549	-2576	-3471	-4308

Table S4. The same as Table S3 but for ozone.

Provinces	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
Anhui	126	41	221	314	324	341	375
Beijing	-55	-120	-52	252	436	510	510
Chongqing	195	204	235	161	129	106	191
Fujian	197	194	58	50	-2	-92	-36
Gansu	144	139	129	99	65	56	17
Guangdong	447	474	114	-374	-832	-980	-1038
Guangxi	256	331	316	-9	-145	-336	-393
Guizhou	240	348	459	276	144	13	-6
Hainan	35	59	74	10	26	0	-26
Hebei	-67	-322	-154	641	1184	1473	1476
Heilongjiang	82	38	68	-31	-8	-21	1
Henan	107	279	531	1028	1323	1461	1650
Hubei	332	283	412	338	327	269	351
Hunan	261	372	403	273	302	177	257
Jiangsu	-99	-153	352	726	861	934	904
Jiangxi	249	166	181	53	57	-59	-76
Jilin	68	41	49	46	40	20	42
Liaoning	64	16	-8	114	114	109	164
Nei Mongol	-77	-63	-36	93	87	88	112
Ningxia Hui	35	30	27	21	22	12	-3
Qinghai	31	29	19	15	2	-2	-16
Shaanxi	168	150	247	403	435	423	521
Shandong	161	-176	348	307	692	1103	1420
Shanghai	-16	-1	77	149	176	181	163
Shanxi	-64	-20	61	402	566	634	665
Sichuan	476	728	829	508	367	339	526
Tianjin	-61	-162	-15	163	369	486	516
Xinjiang Uygur	22	38	-41	-42	-47	-30	8
Xizang	4	5	4	0	5	3	1
Yunnan	162	309	292	155	30	-43	-69
Zhejiang	56	72	239	291	365	342	330

- The authors may want to build few relevant emission scenarios and estimate their impact on $PM_{2.5}/O_3$ exposure in China and in downwind countries (eg. APPCAP is twice as effective in curbing emissions). This might inform the decision makers about the benefits of further curbing emissions in China.

  Response: We thank the reviewer's suggestion. Our study was designed to investigate the influence of realistic emission changes happening in China from 2010 to 2017, including both increasing and decreasing trend, on domestic and downwind regions' air quality. Incorporating other hypothetical emission change scenarios seems to not in the same scope of our objectives. So we decide to keep the current scenarios as they are.

Minor comments

- Line 190- please reconstruct the sentence
  Response: change as suggested. The new sentence is below:

  "At the national-scale, the Pop-weighted $PM_{2.5}$ concentration features a similar trend as the area-weighted average trend, but is notably higher (Fig. 1a), indicating that higher $PM_{2.5}$ concentrations happen in regions with higher population density."

- Line 198- please add the changes due to emission changes in the corresponding years
  Response: we now add the changes due to emission changes. Please see the new sentence below:
  "Relative to 2010, inter-annual meteorology led to annual $PM_{2.5}$ decreases as high as 4.4 µg m^{-3} in 2011, and increases as high as 3.1 µg m^{-3} in 2015. Meanwhile, the emission changes led to annual $PM_{2.5}$ decreases as high as 16.7 µg m^{-3} in 2017, and increases as high as 4.9 µg m^{-3} in 2015 (Fig. 4a)."