Dear Editors and Reviewers,

Thank you very much for your letter and for the reviewers' comments concerning our manuscript entitled "Impacts of emission reduction and meteorological conditions on air quality improvement during the 2014 Youth Olympic Games in Nanjing, China" (doi:10.5194/acp-2017-114). Your comments are all valuable and very helpful for revising and improving our paper, as well as the important guiding significance to our researches. We have studied the comments carefully and have made corrections which we hope meet with approval. Based on the instructions, we have uploaded the file of the revised manuscript.

Appended to this letter is our point-by-point response to the reviewers' comments, the change list and the marked-up manuscript.

We would like to thank you for allowing us to resubmit a revised copy of the manuscript. We hope that the revised manuscript is accepted for publication in ACP.

Sincerely,

Qian Huang

Responses to the reviewers' comments:

Dear Reviewers,

Thank you very much for reviewing the manuscript and providing us the constructive comments and suggestions on our study. We have learned a lot from your advice and revised the manuscript. According to the Comment 5 from Reviewer 2, there might be some problem in Fig.8 in Section 3.3 (old manuscipt). And we carefully checked our data processing, simulation scenarios, and emission inventory, and found that the emission inventory used in Exp.1 (under emission control) had some problem with some points larger than those in the emission inventory before emission control. We're so sorry about that. We have corrected the problem, redone the model simulation of Exp.1, and reprocessed the data. And the model simulation data related to emission reduction are modified in the revised manuscript. Thank you very much for your understanding.

We have studied your comments carefully and have made corrections which we hope meet with approval. And point-by-point response to your comments are listed as below.

Sincerely,

Qian Huang

Reviewer 1

Comment 1: This manuscript described a study for the emission control scenario during the 2nd Youth Olympic Games in Nanjing using surface measurements and WRF/CMAQ model. This manuscript's English need improvement. It listed both model and measurement results, but it is not easy to track which is about observation and which is about the model. I suggest add something to make it clear. For instance, the title of section 3.1 can be "Observed air quality during YOG", and the section 3.2 changes to be "simulated impact of meteorological conditions".

Response: Thank you for your advice. We have followed your advice and modified the manuscript to make observation part and modeling part more clearly. The title of section 3.1 can be "Observed air quality during YOG", and the section 3.2 changes to be "simulated impact of meteorological conditions".

Comment 2: Another issue is that the discussions for the measurements and model are totally separated, and the modeled impact of NO_x emission reduction on O_3 et al is not supported by the observation. Obviously the model or emission inventory has some biases, which should be addressed.

Response: Thank you for your advice. The measurements and model are separated because we want to investigate the variations of air pollutants from different point of view, one is the real reduction of air pollution from observation, the other is model reduction from meteorology and emission.

The observational decrease of O_3 may due to the meteorological conditions. In Aug. 2014, there were more overcast days, and the reduction in solar radiation could restrain the production of O_3. However, in the model simulation, underestimation of cloud cover could result in more solar radiation, which was conductive to the promotion of O_3. Besides, reduction of NO_x could result in less titration of O_3 by NO_x, which also lead to higher simulation O_3. Thus, the observational O_3 variation and the model simulation O_3 variation are different, which was discussed in section 3.3.

Comment 3: Another issue is that this study did not discuss anything about emission and pollutant concentrations in surrounding areas, which sometimes can affect your results.

Response: Thank you for your comment. During the YOG holding month (Aug. 2014), though the surrounding area of Nanjing had taken part in the pollution emission control, their magnitudes of emission reduction were very small. And the emission reduction were mainly concentrated in the holding city, Nanjing, so we focus on the local emission and pollutant concentrations.

Comment 4: Page 1, line 27, "However, simulation" better to be "However, the model simulation"

Response: We are grateful for your suggestion. We have followed your advice and modified the manuscript (Line 27, Page1).

Comment 5: Page 1, line 28, "and raised SO_2" better to be "and could increase"

Response: We have modified it according to the comment (Line 29, Page1).

Comment 6: Page 2, line 48-49, "Preparatory work were carried out since 1 Jul., 2014" better to be "The preparation started from Jul. 1, 2014".

Response: We have changed it according to the suggestion (Line 48-49, Page 2).

Comment 7: Page 2, line 54-59. Please consider to split that long sentence to several sentences as it has grammar errors.

Response: Thank you for your advice. We have followed your suggestions and modify the manuscript. And the sentences (Line 52-57, Page 2) have been rephrased as follows:

Some local petrochemical, chemical and steel industries were forced to limit or halt their production. Coal-combustion enterprises were required to use high-quality coals with low sulfur content and ash content. And heavy pollution vehicles called “yellow label buses” were prohibited in Nanjing during 10-28 Aug.. Oil loading and unloading operations were strictly controlled. Construction process was forced to stop.

Comment 8: Page 4, line 137. “Exp.3 had the same inventory as Exp.2 but the weather” better to be “Exp.3 had the same inventory as Exp.2 but used the weather”

Response: We have changed it according to the suggestion (Line 203, Page 8).

Comment 9: Page 4, line 141. “meteorology on contaminants” better to be “meteorology on air quality”.

Response: We have changed it according to the suggestion (Line 206, Page 8).

Comment 10: This manuscript should show a map of the emission reduction for Exp1 - Exp2, instead of just modeled concentration changes.

Response: Thank you for your advice. We have add some introduction of the emission inventory used in model simulation in Section 2.3 Emissions and simulation scenarios and offer the map (See Fig.2) of the emission reduction for Exp.1 - Exp.2.

Comment 11: Page 8, line 184, “most species had a good reflection”, What does it mean?

Response: Thank you for your comment. We’re sorry about the confusing sentence and have rewritten it. It means the concentrations of most species decreased obviously in Aug. 2014 compared with those in Jul. 2014 and Sept. 2014 (Line 249, Page 11).

Comment 12: Page 8, line 186-194. Please re-write to make it easy to understand.

Response: Thank you for your suggestion. We have rewritten the sentences (Line 251-260, Page 11).

Comment 13: Figure 6, 7 and the corresponding discussion in section 3.2. Are those comparisons for monthly averaged value, such as 10m wind, PBL heights? If so, please state it.

Response: Thank you for your comment. We have completed the captions of the figure (Line 325-328). And Figure 7 shows hourly average values of impact percentage (dspecies (%)= (Exp.2 - Exp.3)/Exp.2 * 100%) of SO_2, NO_2, PM_{10}, $PM_{2.5}$, CO, and O_3, respectively. To better display the bias of meteorological parameters, Figure 6 was replaced by Figure 8 in the revised manuscript (Line 329-334, Page 16), they're hourly average values.

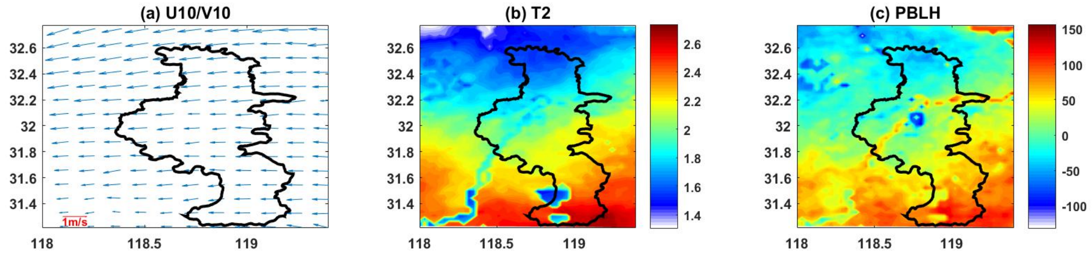

Fig. 8. Bias of simulated hourly mean meteorological conditions during the YOG. (Bias = Meteorological Factors in 16-28 Aug., 2013 - Meteorological Factors in 16-28 Aug., 2014. (a) Bias of Wind at 10m during 16-28 Aug. (unit: m/s), (b) Bias of temperature at 2m during 16-28 Aug. (unit: K), (c) Bias of planetary boundary layer height during 16-28 Aug. (unit: m)).

Comment 14: Page 13, line 257-259. The O_3 increase should be due to the NOx emission reduction -> less titration.

Response: Thank you for your comment. We have corrected it (Line 340-342, Page 16) as follows:

"As for O_3, the variation was positive, especially in the downwind area of NO_x heavy reduction region, which might due to the less titration of O_3 by NO_x"

Comment 15: Page 14, table 6. Why the modeled impact of the emission reduction on NO_2, O_3, PM_{10}, $PM_{2.5}$ diff significantly from the observations? You may discuss it.

Response: Thank you for your suggestion.

As discussed in Section 2.3 (Line 197-206), the simulation scenarios are reasonable. And the dynamic parameterization in WRF as well as the physical and chemical schemes of CMAQ applied in this research were the same as those in the research of Shu et al.(Shu is a member of our research group). The model performance has been validated by Shu et al., and they proved that WRF/CMAQ is reliable as shown in the following two pictures.

Table 3. Comparisons between the simulations and the observations at Shanghai, Nanjing and Hangzhou stations during 4–15 August 2013.

Site[a]	Vars[b]	Mean		R^c	NMB[f]	RMSE[g]
		OBS[c]	SIM[d]			
SH	T_2 (°C)	33.27	31.38	0.91	−5.68 %	4.15
	RH_2 (%)	57.91	65.23	0.85	12.64 %	19.3
	$Wspd_{10}$ ($m\,s^{-1}$)	4.59	4.66	0.77	1.53 %	2.18
	$Wdir_{10}$ (°)	176.34	182.57	0.63	3.53 %	41.44
	O_3 (ppb)	87.77	82.5	0.81	−6.00 %	38.79
	NO_2 (ppb)	29.01	38.25	0.54	31.85 %	28.95
NJ	T_2 (°C)	32.95	30.98	0.84	−5.98 %	2.91
	RH_2 (%)	63.28	66.14	0.83	4.52 %	9.41
	$Wspd_{10}$ ($m\,s^{-1}$)	3.21	3.4	0.74	5.92 %	2.41
	$Wdir_{10}$ (°)	197.68	194.58	0.57	−1.57 %	71.19
	O_3 (ppb)	69.7	78.15	0.81	12.12 %	36.8
	NO_2 (ppb)	41.44	40.09	0.61	−3.26 %	22.4
HZ	T_2 (°C)	33.25	31.08	0.8	−6.53 %	3.09
	RH_2 (%)	52.76	61.39	0.78	16.36 %	13.96
	$Wspd_{10}$ ($m\,s^{-1}$)	3.04	3.32	0.75	9.21 %	2.39
	$Wdir_{10}$ (°)	186.45	186.2	0.58	−0.13 %	69.44
	O_3 (ppb)	76.57	84.51	0.83	10.37 %	33.95
	NO_2 (ppb)	31.06	27.21	0.66	−12.40 %	16.86

[a] Site indicates the city where the observation sites locate, including Shanghai (SH), Nanjing (NJ) and Hangzhou (HZ). [b] Vars indicates the variables under validation, including 2 m air temperature (T_2), 2 m relative humidity (RH_2), 10 m wind speed ($Wspd_{10}$), 10 m wind direction ($Wdir_{10}$), ozone (O_3) and nitrogen dioxide (NO_2). The words between the parentheses behind variables indicate the unit. [c] OBS indicates the observation data. [d] SIM indicates the simulation results from WRF/CMAQ. [e] R indicates the correlation coefficients, with statistically significant at 95 % confident level. [f] NMB indicates the normalized mean bias. [g] RMSE indicates the root-mean-square error.

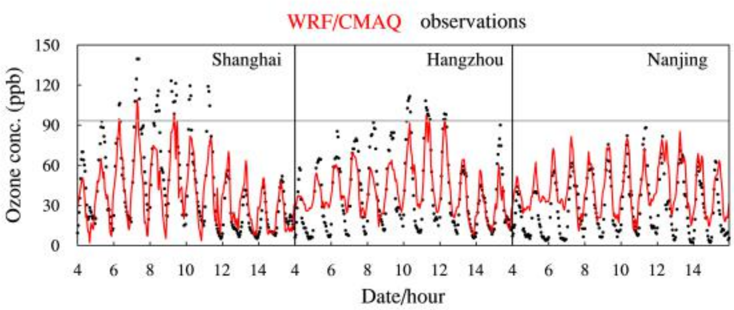

Figure 6. Hourly variations of the observed and the simulated O_3 concentrations in Shanghai, Nanjing and Hangzhou during 4 to 15 August 2013. The red solid lines show the modeling results, the black dot lines give the observations, and the solid gray lines represent the national standard for the hourly O_3 concentration, which is 200 $\mu g\,m^{-3}$.

Several factors contribute to the bias of NO_2, O_3, PM_{10}, $PM_{2.5}$ between simulation and observation. Firstly, a overall underestimation of emission reduction might result in less variations of NO_2, PM_{10}, and $PM_{2.5}$ caused by emission abatement. Secondly, the observational O_3 decreased during the emission control month (Aug. 2014) while the simulation O_3 increased slightly under emission control, which can be affected by the cloud simulation and the modeling chemical mechanism. During Aug. 2014, there were more overcast days, which may cause less solar radiation and was adverse for the promotion of O_3. However, the underestimation of modeling cloud cover could lead to higher simulation O_3. Besides, reduction of NO_x could result in less titration of O_3 by NO_x, and overestimation of this chemical mechanism could also lead to higher simulation O_3.

What's more, the aim of Table 6 (Page 18) is to compare the simulated effect of meteorological conditions and emission reduction other than comparing the simulation with the observation. It want to indicate that the adverse meteorological conditions in Aug. 2014 could cause the increase of pollution concentrations while emission reduction could help to cut down the pollutants' (SO_2, NO_2, CO, PM_{10}, and $PM_{2.5}$) level during Aug. 2014.

Reviewer 2

Comment 1: line 112-113, 'the 9 state controlling air sampling sites in

Nanjing were chosen to represent the whole Nanjing'. Looking at fig 1b, I found 9 stations almost concentrate in the urban area, which is small compared with the whole Nanjing, so I doubt the 9 sites can represent the whole Nanjing, and it's better to collect some observations at rural sites of Nanjing for model validation.

Response: Thank you for your comment. Your suggestion is reasonable, but the limitation is that there are only 9 state controlling air sampling sites in Nanjing as shown in the paper. Among them, XL site is regarded as a suburban site, while CCM site is regarded as an urban site. Besides, the Nanjing Municipal Environmental Protection Bureau takes the 9 state controlling air sampling sites to represent the whole Nanjing and issues Nanjing Air Quality Daily Report. So we think it may be better to follow the local EPA. The details about choosing the sites have been added in Section 2.2 (Line 151-155, Page 5).

Comment 2: Line 149-160 presents the comparison between Aug. 2014 and Aug. 2013 and states' emission reductions did help the alleviation of air pollution......' , you didn' t look at and discuss the difference in meteorological conditions between the two years, how can you rule out the potential influence of meteorology, so please add meteorology comparison here. Also, there are evident emission reductions during Aug. 2014, with 22.1% for SO_2, 12.5% for NO_x, and 21.4% for $PM_{2.5}$, why the decrease in $PM_{2.5}$ concentration at CCM is just 9.8%, how about the proportion and relative changes of primary and secondary PM2.5?

Response: Thank you for your suggestion. We have reorganized this part (Line 222-228). And we have followed your advice and comparison of meteorological conditions is in Section 3.2.

The emission reduction percentages are the mean of the whole city, the details of emission reduction are added in Section 2.3 Line 173-195. However, the distributions of emission reduction are not uniform since the intensities of emission reduction are different from various trades. Also, the relationship between pollutant source and pollutant concentration is not linear. Thus, the decrease in $PM_{2.5}$ concentration at urban site CCM is not very big. The $PM_{2.5}$ observational data is total $PM_{2.5}$, so we can't distinguish the proportion and relative changes of primary and secondary $PM_{2.5}$.

Comment 3: Line 182-191, when comparing simulations in Aug. 2014 with that in Jul. and Sept. 2014, you try to say the pollutant concentrations declined with emission control, but rebounded after releasing control, however, the simulated SO_2 concentration in Aug. is larger than that in Jul. (5.1%), whereas NO_2 (19.8%) and CO (21.1%) in Aug. are larger than in Sept., how do you explain the larger SO_2, NO_2 an CO concentrations in Aug. although strict emission abatement is implemented than those in Jul. and Sept. with no emission reduction?

Response: Thank you for your comment. Firstly, this paragraph compares the observational data other than simulations in Aug. 2014 with that in Jul. and Sept. 2014. Secondly, we're sorry that there is a mistake in Line 190 (old manuscript): "the change percentage of species (SO_2, NO_2, PM_{10}, $PM_{2.5}$, CO and O_3) was -37.4%, 19.8%, -37.6%, -22.3%, 21.1%, and -47.2%, respectively at CCM station (Table 4)", "19.8%" should be "-19.8%", and we have corrected it (Line 259-260). Thirdly, Table 4 and Table 5 show the observational pollutants variations other than simulated pollutants variations in Jul., Aug. and Sept. at CCM station and XL station. We can see that at XL station (a suburban station), the concentrations of all species (SO_2, NO_2, PM_{10}, $PM_{2.5}$, CO, and O_3) in Aug. are the lowest compared to those in Jul. and Sept.. Besides, at CCM station (a urban station), the concentrations of most species (NO_2, PM_{10}, $PM_{2.5}$, and O_3) are the lowest compared to those in Jul. and Sept.. These show a pollutant concentration decline trend after emission control and a rebound trend after releasing control. Besides, at CCM station, the observational SO_2 concentration in Aug. is larger than that in Jul. (5.1%), whereas CO (21.1%) in Aug. are larger than in Sept., which could be caused by many factors, such as traffic and other unpredictable emissions around the site. As for traffic control, only the heavy pollution vehicles called "yellow label buses" were prohibited in Nanjing during 10-28

Aug.. To meet the traffic demand of numerous tourists, athletes, and freightage, there could be more traffic pollution and raised the level of SO_2, NO_x and CO. Besides, NO_x was mainly emitted from power plants, so the overall NOx was the lowest during the emission control month. However, they don't bother the overall variation trend of the six species.

Comment 4: line 227-228, ' Consequently, Exp.2 resulted in higher pollutant concentrations for all species as shown in Fig.7', this is not true, although the domain averages of pollutant values increase from Exp3 to Exp2, it is apparent that the spatial distribution did not show a consistent increase in the domain, such as the large decreases in all components but O_3 to the northeast, and the decreases in SO_2, NO_2, CO, O_3 in portions of Nanjing, so the meteorological condition in Aug. 2014 did not necessarily lead to increases in pollutant levels, so I suggest more discussion on the different responses to meteorology in the domain with analysis of meteorological variable changes.

Response: Thank you for your comment. This paper tries to discuss the overall impact of meteorological conditions. Based on Fig.7, statistics show that meteorology in Aug. 2014 led to total increases in pollutant levels. Line 301-302 offer the details : "For SO_2, NO_2, PM_{10}, $PM_{2.5}$, CO, and O_3, their concentrations were increased by 17.5%, 16.9%, 19.0%, 19.5%, 7.8% and 0.8%". Factors such as topography could affect locally, and may cause discontinuous increases in Fig.7 , but it did not affect the overall increase trend. So, partial decrease is not that important. The analysis of meteorological variable changes was in Line 303-314.

Comment 5: section 3.3, similar problems in this section, when emission reduction lead to apparent decreases in concentrations of all pollutants except O_3, how do you explain the apparent increases in the southern parts of Nanjing (Fig. 8)? are there some feedbacks among aerosols, radiation (photolysis), cloud and consequent effects on chemical processes, please elaborate on mechanisms behind these changes instead of just presenting model results.

Response: Thank you for your comment. The mechanisms about meteorology have been discussed in Section 3.2. In Section 3.3, the apparent increases of (SO_2, NO_2, PM_{10}, $PM_{2.5}$ and CO) in the southern parts of Nanjing seems unreasonable. To find out the reason, we carefully checked our data processing, simulation scenarios, and emission inventory. We found that the problem was not caused by meteorology but the emission inventory. The emission inventory used in Exp.1 (under emission control) had some problem with some points larger than those in the emission inventory before emission control. The emission under control should not exceed the emission before control. We are sorry about that. We have corrected the emission inventory (under emission control), redone the model simulation of Exp.1 and reprocessed the data. And the corrected figure (See Section 3.3, Fig.9) as shown below don't have increases (SO_2, NO_2, PM_{10}, $PM_{2.5}$ and CO) in the southern of Nanjing. Besides, emission reduction led to completely decrease (SO_2, NO_2, PM_{10}, $PM_{2.5}$ and CO) in the whole city, and increase of O_3 in Nanjing. The drop of O_3 was due to the reducing NO_2 and less titration impacts.

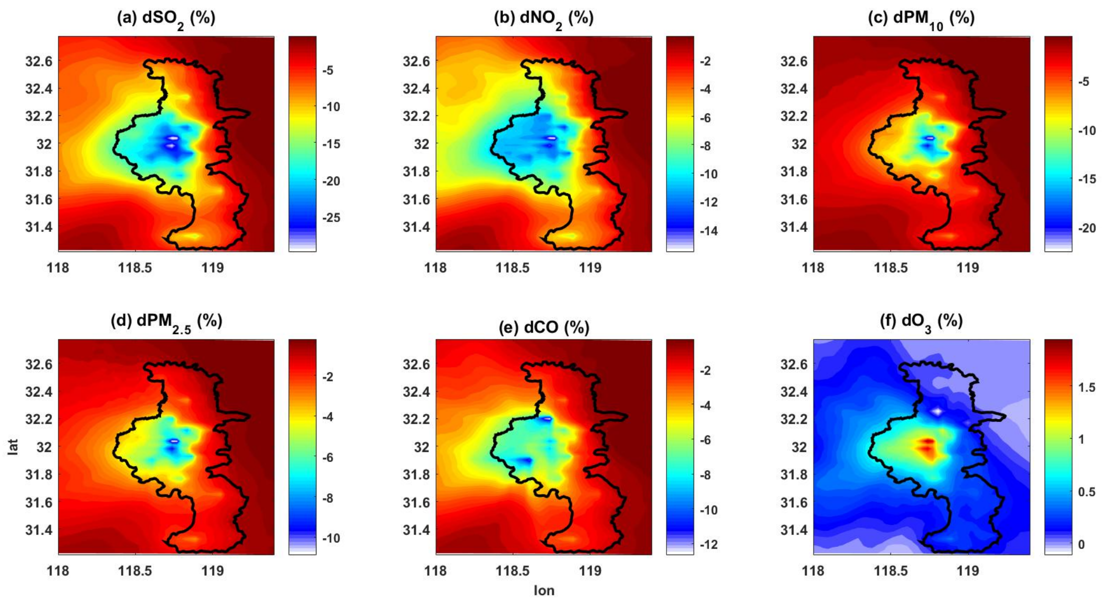

Fig. 9. Influence of emission reduction on hourly mean concentrations of pollutants in Aug. 2014. (Black thick lines draw the outline of Nanjing. Picture a - f are hourly average values of impact percentage (dspecies (%) = (Exp.1 - Exp.2)/ Exp.2*100%) of SO_2, NO_2, PM_{10}, $PM_{2.5}$, CO and O_3, respectively.).

Comment 6: Regarding Fig.9, please explain how the meteorological change lead to day-to-day variations (either increase or decrease) of pollutant concentration.

Response: Thank you for your comment. The old Fig.9 is the current Fig.10 in section 3.4, it aims to compare the simulated effect of meteorology and emission reduction from day to day during the YOG other than to explain how meteorological change lead to day-to-day variations. From Fig.10 , we can see that emission control caused decreases of pollutant (SO_2, NO_2, PM_{10}， $PM_{2.5}$, and CO) concentration while meteorology caused increases of pollutant (SO_2, NO_2, PM_{10}, $PM_{2.5}$, CO and O_3) concentration in most of the time.

Comment 7: Some tables like Table 4 and 5 can be removed because this manuscript is not a data report.

Response: Thank you for your advice. Table 4 and Table 5 are statistical analysis of observational data, we think they're important and retain them may be better.

Comment 8: Please describe clearly the spatial and time scales of the presented data or model results and the comparison between cases throughout the manuscript, such as line 266 ’ Fig.9 displays the effect of meteorological factors and emission reduction’ , please write clearly the numerical experiments, the time period and which domain for average etc.

Response: Thank you for your advice. The old Fig.9 is the current Fig.10. We have rewritten the sentence as "Fig.10 displays the effect of meteorological factors and emission reduction in Nanjing on air quality improvement during YOG (12-28 Aug., 2014). ” (Line 351-352). And the caption of Fig. 10 (Line 359-261) has been changed as “Fig. 10. The simulated effect of meteorology and reduction on pollutant concentrations in Nanjing during the YOG (16-28 Aug. , 2014), Met. (Exp.2-Exp.3) represents the simulated effect of meteorology, while Red. (Exp.1-Exp.2) represents the simulated effect of reduction.”. Besides, the details of numerical experiments were stated in section 2.3 Line 200-206.

Comment 9: The English in this manuscript should be carefully checked and much improved by correcting grammatical errors and rewording sentences, some of them are misleading and ambiguous.

Response: Thank you for your advice. The co-authors have helped to modify and improve the English in the manuscript carefully.

Reviewer 3

General Comments:

Comment 1: This paper tried to evaluate the impacts of emission reduction and meteorologicalconditions on the air quality improvement during an air pollution control period-YOG of Nanjing. Accurate quantification of the influence of emission reduction and meteorological conditions is important to evaluate the air pollution control measures. This paper used both observation data and modeling results to address this issue. However, this manuscript has major writing and structure problem. The validation of model simulation and uncertainty analysis is essential and required but lack in the manuscript.

Response: Thank you for your comment. We have extended the model description part in Section 2.2, in this part, we explained that the dynamic parameterization in WRF as well as the physical and chemical schemes of CMAQ applied in this research were the same as those in the research of Shu et al. (Shu is a member of our research group) and were proven to have good simulation performance. So we no longer validate the model performance and uncertainty in this paper.

The following table and figure are the evaluation of WRF/CMAQ performance from Shu et al. (2016). The table presents the performance statistics, including the values of R, the NMB and the RMSE, which are all calculated for 2 m air temperature (T_2), 2 m relative humidity (RH_2), 10 m wind speed ($Wspd_{10}$), 10 m wind direction ($Wdir_{10}$), surface O_3 concentrations and surface NO_2 concentrations in Shanghai (SH), Nanjing (NJ) and Hangzhou (HZ), China. As indicated in the table, the simulated results of surface air temperature and relative humidity from WRF show good agreement with the observations. The highest correlation coefficient of T_2 is found to be 0.91 at SH, followed by 0.84 at NJ and 0.80 at HZ (statistically significant at 95 % confident level). The corresponding correlation coefficients for RH_2 are 0.85, 0.83 and 0.78, respectively. The values of RMSE for T_2 at SH, NJ and HZ are 4.15, 2.91

and 3.09 ◦C and those for RH_2 are 19.3, 9.41 and 13.96 %, respectively. The simulation underestimates T_2 and overestimates RH_2 to some certain extent, however, they're reasonable and acceptable compared to some relevant studies. Besides, the table indicates that the simulation of $Wspd_{10}$, $Wdir_{10}$, and concentrations of pollutants are also reliable. The following figure shows the comparisons between the modeling results from CMAQ and the observed hourly concentrations of O_3 in Shanghai, Nanjing and Hangzhou during 4-15 Aug. 2013. Obviously, the observations and the simulated results present reasonable agreement at each site, with the correlation coefficients of 0.81 to 0.83, NMB of −6 to 12.12 % and RMSE of 33.95 to 38.79 ppb. Moreover, the simulation also reproduces the diurnal variation of O_3, which shows that the concentration reaches its maximum at around noontime and gradually decreases to its minimum after midnight.

Table 3. Comparisons between the simulations and the observations at Shanghai, Nanjing and Hangzhou stations during 4–15 August 2013.

Site[a]	Vars[b]	Mean		R[e]	NMB[f]	RMSE[g]
		OBS[c]	SIM[d]			
SH	T_2 (°C)	33.27	31.38	0.91	−5.68 %	4.15
	RH_2 (%)	57.91	65.23	0.85	12.64 %	19.3
	$Wspd_{10}$ (m s^{-1})	4.59	4.66	0.77	1.53 %	2.18
	$Wdir_{10}$ (°)	176.34	182.57	0.63	3.53 %	41.44
	O_3 (ppb)	87.77	82.5	0.81	−6.00 %	38.79
	NO_2 (ppb)	29.01	38.25	0.54	31.85 %	28.95
NJ	T_2 (°C)	32.95	30.98	0.84	−5.98 %	2.91
	RH_2 (%)	63.28	66.14	0.83	4.52 %	9.41
	$Wspd_{10}$ (m s^{-1})	3.21	3.4	0.74	5.92 %	2.41
	$Wdir_{10}$ (°)	197.68	194.58	0.57	−1.57 %	71.19
	O_3 (ppb)	69.7	78.15	0.81	12.12 %	36.8
	NO_2 (ppb)	41.44	40.09	0.61	−3.26 %	22.4
HZ	T_2 (°C)	33.25	31.08	0.8	−6.53 %	3.09
	RH_2 (%)	52.76	61.39	0.78	16.36 %	13.96
	$Wspd_{10}$ (m s^{-1})	3.04	3.32	0.75	9.21 %	2.39
	$Wdir_{10}$ (°)	186.45	186.2	0.58	−0.13 %	69.44
	O_3 (ppb)	76.57	84.51	0.83	10.37 %	33.95
	NO_2 (ppb)	31.06	27.21	0.66	−12.40 %	16.86

[a] Site indicates the city where the observation sites locate, including Shanghai (SH), Nanjing (NJ) and Hangzhou (HZ). [b] Vars indicates the variables under validation, including 2 m air temperature (T_2), 2 m relative humidity (RH_2), 10 m wind speed ($Wspd_{10}$), 10 m wind direction ($Wdir_{10}$), ozone (O_3) and nitrogen dioxide (NO_2). The words between the parentheses behind variables indicate the unit. [c] OBS indicates the observation data. [d] SIM indicates the simulation results from WRF/CMAQ. [e] R indicates the correlation coefficients, with statistically significant at 95 % confident level. [f] NMB indicates the normalized mean bias. [g] RMSE indicates the root-mean-square error.

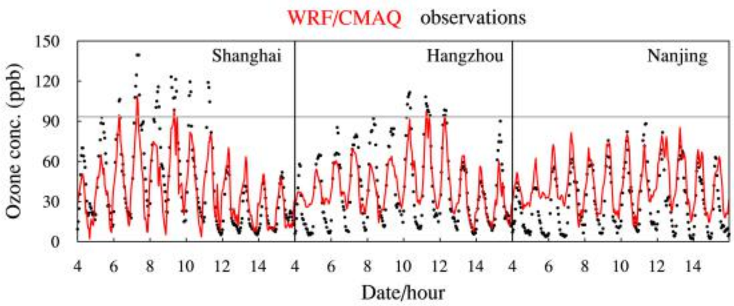

Figure 6. Hourly variations of the observed and the simulated O_3 concentrations in Shanghai, Nanjing and Hangzhou during 4 to 15 August 2013. The red solid lines show the modeling results, the black dot lines give the observations, and the solid gray lines represent the national standard for the hourly O_3 concentration, which is 200 µg m^{-3}.

Comment 2: The paper lacks in-depth discussions of the observation data and model results. Some conclusions are too arbitrary and lack sufficient evidence to back the interpretations of the results (see detail comments below).

Response: Thank you for your comment. This paper tries to apply model simulations to investigate the reason why observation pollutant concentration changes. We have studied your comment and added some discussion in-depth about the results in the revised manuscript.

Comment 3: The literature review in the introduction section needs improvement.

Response: Thank you for your comment. According to your detail comments, we have improved the introduction section in the revised manuscript.

Comment 4: The quality of English needs substantial improving. I believe that the paper needs substantial revisions before considering to be published at ACP.

Response: Thank you for your comment. The co-authors have helped to improve the English of the paper, and some sentences have been rewritten and reorganized.

Detail Comments

Comment 1: Line 22-26 This sentence here is not rigorous. What concentration? Hourly average? Daily average? From what data? Observation data at which site? You'd better give the standard deviations of the data.

Response: Thank you for your comment. We're sorry about the ambiguous expression. They're the hourly average observational concentrations. And they are the mean of the two representative sites in Nanjing. We have rewritten the sentences as follows:

"During the YOG holding month (Aug., 2014), the hourly mean observational concentration of SO_2, NO_2, PM_{10}, $PM_{2.5}$, CO and O_3 was 11.6 μg/m^3, 34.0 μg/m^3, 57.8 μg/m^3, 39.4 μg/m^3, 0.9 mg/m^3, and 38.8 μg/m^3, respectively, which were below China National Ambient Air Quality Standard."

Besides, we have added some explanation in Section 3.1 Observed air quality during YOG (See Line 214-217, Page9). And the standard deviations of the data was given in Section 3.1.

Comment 2: The introduction section should be rewritten and reorganized. The references cited in the introduction section should be more targeted and well selected. Take Line 78-82 for example, the references cited here have nothing to do with the topic of the paper. Line 60-82, too many references are cited without summary and in-depth understanding.

Response: Thank you for your comment. The references cited in the introduction section are mainly discussing the impact of emission reduction or meteorology on air quality in social events, like Beijing Olympic Games, the 16th Asian Games in Guangzhou and the World Expo in Shanghai. And some discussed the air pollution characteristics in Yangtze River (where Nanjing locates). All of them have reference value to our research. Line 78-79 "Xu et al. (2013) concluded that $PM_{2.5}$ was mainly emitted from anthropogenic sources other than biogenic sources." related to the impact of emission reduction, it indicated that cut down anthropogenic sources could decrease $PM_{2.5}$ in the air. Line 79-80 "Dong et al. (2013) found that independent NO_x emission reduction would strengthen O_3 as a side effect in YRD." helped to explained the simulated increase of O_3 in our research. Some introduction of references might be simple or not very important, we have modified them and added some references. The modified sentences are in Line 60-90.

Comment 3: Section 2.2, Fig.1 is hard to read. The authors stated that the 9 stations were chosen for representing the whole Nanjing city. But all of the 9 stations located at the center part of the city. I doubt can they represent the whole city? Moreover, what is the purpose of these sites? For model validation? Please give the results of model validation.

Response: Thank you for your comment.

There are only 9 state controlling air sampling sites in Nanjing as shown in this paper. They locate in different districts of Nanjing. And the density of population, traffic conditions and economics can differ a lot in different district, for example, the urban district Gulou District (where CCM station locates) and suburb district Xianlin District (where XL station loctes).

In this condition, Nanjing Municipal Environmental Protection Bureau chooses the local 9 state controlling air sampling sites to represent the whole Nanjing city. In conformity with this, we chose the 9 state controlling air sampling sites to represent the whole Nanjing while analyzing model simulation impacts.

Thus, they're not use for model validation. The details about model validation have been answered in the General Comment Response part (General Comments, Comment 1).

Besides, we have added the reason why we choose the 9 sites in the revised manuscript (Line 151-155, Page6).

Comment 4: Section 2.3 The description here is quite ambiguous. Which year of the emission inventory is used for simulation? How do the authors make the emission inventory after reduction? How to determine the reduction ratio? Based on the control measures? Is there any hypothesis here? If there is hypothesis? What is the uncertainty? Please state the experimental process in detail.

Response: Thank you for your advice. We have added the detail about how the innermost domain emission inventories were set in Section 2.3 (Line 173-187) in the revised manuscript.

The inventory before emission control was based on the local emission in 2012. According to the control measures offered by the local Environmental Protection Agency (EPA), we made the emission inventory under emission control. The emission control measures include all coal-combustion enterprises must use high-quality coals with low sulfur content less than 0.5% and ash content less than 13%, over 100 local petrochemical, chemical and steel enterprises were forced to cut or halt their production during Aug. 2014, and heavy pollution vehicles called “yellow label buses” were prohibited. And more details about emission control measures like the reduction ratios of some enterprises were in *2014 Youth Olympic Games Nanjing Environmental Air Quality Assurance and Emergency Response Program* offered by the local EPA. So, there could still be some bias with the emission inventories used in model simulation.

Comment 5: Section 3.1 The title of this section is inconsistent with the content. Why CCM and XL station are chosen for study? Can they represent the whole study area of the modeling or Nanjing (same as detail comments NO.3)? The data analysis in this section should be more rigorous and more in-depth. Line 147-148 How to get the reduction percentage? Calculate from observation data or other ways? Line 154-156 Why the authors avoid discussion of NO_2 at CCM and CO at XL? Line 157-158 The discussion here is inaccurate. The deviation of PM_{10} and $PM_{2.5}$ is larger in 2014. Line 158-160 How to get this conclusion from the analysis above? Line 182-199 Similar problems as above. Line 190-191 The change percentage of NO_2 listed here is 19.8 %, but in Table 4 is -19.8%, please check the correctness and consistency of your results. In line 193-194, the authors said that "the pollutant concentrations declined with emission control, but rebounded after releasing control". How to explain the higher simulated concentrations of SO_2 and CO during Aug. with strictly control measures? The authors listed too many tables in this section without in-depth analysis and solid discussions.

Response: Thank you for your comment. To avoid misunderstanding, we have changed the title as 3.1 Observed air quality during YOG. And the reason why we choose CCM and XL station for study has been added in Section 2.1 Data description (Line 109-123, Page 4). Both of the two stations are state controlling air sampling sites. The data quality assurance and quality control procedures for monitoring strictly follow the national standards (State Environmental Protection Administration of China, 2006). Caochangmen (CCM) Station (118.75 ° E, 32.06 ° N) locates in Gulou District, the city center of Nanjing. Gulou District is the center of economy, politics, culture and education in Nanjing. Here gathers many East China's high-end industrial and corporate headquarters. Besides, over 90% provincial authorities, more than 20 colleges and universities, and more than 120 research institutes situate in Gulou District. It ' s the most populated area in Nanjing, with lively commercial hub and heavy traffic. Thus, CCM station was chosen to represent the urban status of Nanjing. The other station is Xianlin (XL) Station (118.92° E, 32.11° N). XL station locates in Qixia District, the suburb of Nanjing. Compared to Gulou District, Qixia District is much more sparsely populated. And there is no traffic congestion problem in Qixia District. Thus, XL station was chosen to represent the suburban status of Nanjing. The reduction percentages were percentages of the emission sources, the details about the emission reduction were added in Section2.3 Emissions and simulation scenarios (Line 173-195). In the revised manuscript, to prevent misunderstanding, we no longer mention the emission reduction percentage in Section 3.1.

In order to stressed the observational concentration of most species decreased in Aug. 2014, we didn't mentioned the slightly rise of NO_2 at CCM and CO at XL. The slightly rise of NO_2 and CO could be caused by traffic. To meet the traffic demand of numerous tourists, athletes, and freightage, there could be more traffic pollution and raised the level of NO_2 and CO.

Thanks for your correction. Line 157-158 (old manuscript) is inaccurate, the conclusion is not reasonable in Line 158-160 (old manuscript). we have corrected them (See Line 223-225, Page 9) as “Besides, the smaller standard deviation (std) of SO_2, NO_2, CO and O_3 revealed that concentrations of these air pollutants varied more steadily in Aug. 2014. The drop of pollutant concentration could be caused mainly by meteorology conditions or emission reductions. And we will discuss the reason based on model simulations in Section 3.2 and Section 3.3.”. Besides, we have corrected the problem in Line 182-199 (old manuscript), the details are in Line 262-269.

Sorry about the error in Line 190-191 (old manuscript), the change percentage of NO_2 should be -19.8% other than 19.8%, and we have corrected it.

The discussion of this part has been rewritten (Line 249-269). According to Table 4 and Table 5, concentrations of most species decreased in Aug. 2014, but rebound in Sept. 2014. Besides, the simulated concentration of SO_2 and CO during Aug. were not higher. The simulated SO_2 dropped by 24.6% and the simulated CO dropped by 7.2% (See Section 3.3 Simulated impact of emission reduction, Line 338-340) .

Comment 6: Line 221-232, The authors should avoid ambiguous discussion. The word such as “lower temperature and weaker winds”, “rather worse meteorological conditions” is quite obscure to readers.

Line 227, The authors stated “…… which was consistent with the observations”, could you give more detailed comparison results of model and observations? How about the accuracy of the simulated meteorological parameters? Fig. 6, What do “data1” and “data2” stand for?

Response: Thank you for your comment. We have rewritten this section (Section 3.2 Simulated impact of meteorological conditions Line 291-328). In the revised manuscript, the bias of meteorological parameters during the two simulated period were added to explain the different weather conditions. Details about the model performance please see the earlier response to General Comments, Comment 1. “data1” and “data2” means nothing, they should not show in the figure. We're sorry about the mistake, and have redrawn the figure.

Comment 7: How to explain the spatial distributions of the impact percentage? For CO and O_3, the simulated concentrations of Exp.2 are lower than those of Exp.3, especially for the north part of Nanjing city.

Response: Thank you for your comment. “For CO and O_3, the simulated concentrations of Exp.2 are lower than those of Exp.3” is incorrect. And O_3 of Exp.2 was not higher in the north part of Nanjing (Fig.7). Statistically, as for the mean of the whole city and the mean of 9 sites, the simulated CO and O_3 concentrations of Exp.2 are higher than those of

Exp.3. As discussed in Line 302, CO and O_3 were increased by 7.8% and 0.8% (the mean of 9 sites). The decrease of CO in the small section of northern Nanjing didn't bother our conclusion, we are more concern about the overall impact.

Comment 8: Section 3.3, Line 247-248, the statement here is ambiguous. 9.2% and 38.1% is from model results or others? 9.2% to 38.1% is a fuzzy range. Line 249-250, what do you mean? What is the definition of short-lived chemical composition? Line 250-251 How to explain the uneven distribution of the impact percentage? Line 256-257 The reduction ratios here are compared to what period? The authors should give more exact time during the discussion.

Response: Thank you for your suggestion. We're sorry about the ambiguous expression. 9.2% and 38.1% is from emission inventories used for simulations before and after emission control. In the revised manuscript, we have added description about emission inventories in Section 2.3, so we no longer refer the cutting ratios of emission inventories in Section3.3. Line 249-251 (old manuscript) means the uneven distribution of impact percentage was related to the uneven distribution of emission sources and the uneven reduction of emission sources. Thus the large simulation variations (Exp.1 - Exp.2) occurred in the west of Nanjing corresponding to the downwind regions of heavy reduction districts was reasonable.

Short-lived chemical composition refers to the chemical composition whose residence time in the atmosphere is short.

Line 256-257 (old manuscript) The reduction ratios referred to the simulated pollutant concentrations before and after emission control in Aug. 2014 (the holding month of YOG). And the exact time was explained in Line 340.

Comment 9: Section 3.4 Why do you choose 16th Aug. to 28th Aug. not the whole month of Aug. as the study time here? Line 270-271 How can you make the conclusion here? From Fig. 9, it seems that the influence of meteorological conditions is more important for the air quality of Nanjing. Line 278-291 The authors focus on discussing difference of emission reduction influence at two sites. However, 0.9 %, 1.1 % etc. is quite small change. What is the result when considering the uncertainty of the model simulations? Line 299-308 The discussions here lack of evidence.

Response: Thank you for your comment. The old Fig.9 is the current Fig.10. The holding time of YOG is 16th Aug. to 28th Aug., to highlight the impact during the holding time, we choose 16th Aug. to 28th Aug.. As discussed in Section 3.2 Simulated impact of meteorological conditions, meteorological conditions in Aug. 2014 led to increases of pollutant levels compared to those under the conditions in Aug. 2013.

However, the discussion of observational data in Section 3.1 showed that the observational pollutant concentrations were lower in Aug. 2014 compared to those in Aug. 2013. So, we could conclude that the weather conditions in Aug. 2014 were worse than those in Aug. 2013 and might raise the pollutant level, the observational drop of pollutant concentrations in Aug. 2014 compared to those of Aug. 2013 was mainly due to emission reduction.

0.9% and 1.1% (old manuscript) are simulated impact percentage of O_3 at sites. Though they're small , they reflected that meteorology in Aug. 2014 could raise O_3, and emission reduction could also raise O_3 considered the reducing NO_2 and the titration effect. And they still support our conclusion. The details about the simulation model performance are in the previous response (General Comments, Comment 1).

Discussions in Line 299-308 (old manuscript) were according to the emission control measures as introduced in Section 2.3 Line 178-187.

Technical Comments

Comment 1: The authors should refer to "the guidelines for authors" of ACP to prepare the manuscript.

Response: Thank you for your comment. We have carefully read "the guidelines for authors" of ACP and revised the manuscript.

Comment 2: Abbreviations should be given for the first time. Such as "CST" etc.

Response: Thank you for your comment. Sorry about our carelessness. We have revised the manuscript (See Line 197, Page8 "The simulated period was from 27 Jul. to 1 Sept. (China standard time, CST)"). And "CST" means China standard time in this paper.

Comment 3: The date format need to be uniform.

Response: Thank you for your suggestion. We have revised the date format to be uniform.

Comment 4: Spaces must be included between number and unit.

Response: Thank you for your suggestion. We have checked and revised the manuscript.

Comment 5: Fig. 9 The legend makers "Met" and "Red" here are easy to lead misunderstanding. You'd better use "Met." and "Red.".

Response: Thank you for your suggestion. We have corrected them.

Comment 6: The reference format should be uniform. Too many references in Chinese are cited.

Response: Thank you for your suggestion. We have checked and correct the format. Besides, we have added some more references in English and cut some references in Chinese.

Comment 7: The English of this manuscript needs substantial improvement.

Response: Thank you for your comment. The co-authors have helped to improve the English of the manuscript and some sentences have been rewritten and reorganized.

Change list:

1. Line 21, 24-32: Rephrase the Abstract section.

2. Line 45-46: Cite one more reference.

3. Line 48-58, 60-63, 74-92, 99: Rephrase the Introduction section.

4. Line 109-123: Rephrase Section 2.1 Data description.

5. Line 127-143, 146-158: Rephrase Section 2.2 Model description.

6. Line 173-195: Add some details about emission inventories used in model simulations.

7. Line 197, 199, 203, 206: Rephrase the sentences.

8. Line 209-212, 214-217, 221-225, 248-249, 251-260, 262-265, 267-269: Rephrase Section 3.1 Observed air quality during YOG.

9. Line 291-294, 297-300, 303-328: Rephrase Section 3.2 Simulated impact of meteorological conditions.

10. Line 330: Change the Section name as “3.3 Simulated impact of emission reduction”.

11. Line 335, 338-346: Rephrase Section 3.3 Simulated impact of emission reduction.

12. Line 350: Change the Section name as “3.4 Comparison of simulated meteorological factors and emission reduction”.

13. Line 351-352, 360-361, 369-370, 373-376: Rephrase Section 3.4 Comparison of simulated meteorological factors and emission reduction.

14. Line 378-383: Change Table 6 and its caption.

15. Line 390, 392: Rephrase Section 3.4.

16. Line 401, 404-405: Rephrase Section 4 Summary and conclusions.

17. Delete some references as listed below:

Chen, M., Ma, L. M., Wei, H. P., Shi, H., Ma, J. H., Zhou, G. Q, Gu, S. Q., and Zhang, G. L.: Weather impacts on air quality of the World Expo in Shanghai, Journal of Applied Meteorological Science, 24, 140-150, 2013 (in Chinese).

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Huang, Y. M., Wei, H. P., Duan, Y. S., and Zhang, Y. H.: Ambient air

quality status and reason analysis of Shanghai World Expo, Environmental Monitoring in China, 29, 58-63, 2013 (in Chinese).
Li, L., Liu, Q., Li, B., Zhao, Q. Y., and Yao, Y. K.: Assessment of air quality benefits from control measures during Nanjing Youth Olympic Games, Research of Environmental Sciences, 29, 175-182, 2016 (in Chinese).
Mu, Y. Y., Li, W. Q., Yu, Z. H., Yu, Y. Y., Xie, F. J., and Guo, J.: Evaluation of air quality guarantee measures for opening ceremony of YOG, Environmental Science & Technology, 38, 267-271, 2015 (in Chinese).
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Wei Y. X., Tong Y. Q., Yin, Y., Chen, k.: The variety of main air pollutants concentration and its relationship with meteorological condition in Nanjing City, Transactions of Atmospheric Sciences, 32, 451- 457, 2009 (in Chinese).
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18. Add some references as listed belew:

Byun, D. and Schere, K. L.: Review of the governing equations, computational algorithms, and other components of the models-3 Community Multiscale Air Quality (CMAQ) modeling system, Appl. Mech. Rev., 59, 51-77, doi:10.1115/1.2128636, 2006.

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Jiang, F., Zhou, P., Liu, Q., Wang, T. J., Zhuang, B. L., and Wang, X. Y.: Modeling tropospheric ozone formation over East China in springtime, J. Atmos. Chem., 69, 303-319, doi:10.1007/s10874-012-9244-3, 2012.
Li, M. M., Song, Y., Mao, Z. C., Liu, M. X., and Huang, X.: Impacts of thermal circulations induced by urbanization on ozone formation in the Pearl River Delta region, China, Atmos. Environ., 127, 382-392, doi:10.1016/j.atmosenv.2015.10.075, 2016.

Liao, J. B., Wang, T. J., Wang, X. M., Xie, M., Jiang, Z. Q., Huang, X. X., and Zhu, J. L.: Impacts of different urban canopy schemes in WRF/Chem on regional climate and air quality in Yangtze River Delta, China, Atmos. Res., 145, 226-243, doi:10.1016/j.atmosres.2014.04.005, 2014.

Liao, J. B., Wang, T. J., Jiang, Z. Q., Zhuang, B. L., Xie, M., Yin, C. Q., Wang, X. M., Zhu, J. L., Fu, Y., and Zhang, Y.: WRF/Chem modeling of the impacts of urban expansion on regional climate and air pollutants in Yangtze River Delta, China, Atmos. Environ., 106, 204-214, doi:10.1016/j.atmosenv.2015.01.059, 2015.

Lin Y., Huang, K., Zhuang, G., Fu, J. S., Xu, C., Shen, J., and Chen, S.: Air Quality over the Yangtze River Delta during the 2010 Shanghai Expo, Aerosol & Air Quality Research, 13, 1655-1666, doi: 10.4209/aaqr.2012.11.0312, 2013.

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M. G., Zhu, X. S., and Ouyang, Y.: Application of photochemical indicators to evaluate ozone nonlinear chemistry and pollution control countermeasure in China, Atmos. Environ., 99, 466-473, doi:10.1016/j.atmosenv.2014.10.013, 2014.

Xie, M., Liao, J., Wang, T., Zhu, K., Zhuang, B., Han, Y., Li, M., and Li, S.: Modeling of the anthropogenic heat flux and its effect on regional meteorology and air quality over the Yangtze River Delta region, China, Atmos. Chem. Phys., 16, 6071-6089, doi:10.5194/acp-16-6071-2016, 2016.

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19. Revise the date format to be uniform.

20. Correct the grammar throughout the manuscript to make it clear and precise.

21. Add doi to the references which did not include doi in the original

version.

Impacts of emission reduction and meteorological conditions on air quality improvement during the 2014 Youth Olympic Games in Nanjing, China

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Abstract

As the holding city of the 2nd Youth Olympic Games (YOG), Nanjing is highly industrialized and urbanized facing with several air pollution issues. In order to ensure better air quality during the event, the local government took great efforts to control the pollution emissions. However, air quality can still be affected by synoptic weather~~meteorology~~. In this paper, the influences of meteorological factors and emission reductions were investigated using observational data and numerical simulations with WRF/CMAQ. During the YOG holding month (Aug~~ust~~., 2014), the hourly mean observational concentration of SO_2, NO_2, PM_{10}, $PM_{2.5}$, CO and O_3 was 11.6 μg/m^3, 34.0 μg/m^3, 57.8 μg/m^3, 39.4 μg/m^3, 0.9 mg/m^3, and 38.8 μg/m^3, respectively, which were ~~under~~below China National Ambient Air Quality Standard. However, model simulation showed that the weather conditions such as weaker winds during the holding time were adverse for better air quality, and could increase~~raised~~

SO_2, NO_2, PM_{10}, $PM_{2.5}$ and CO by 17.5%, 16.9%, 19.0%, 19.5%, 7.8% and 0.8%, respectively. Taking account of local emission abatement only, simulated SO_2, NO_2, PM_{10}, $PM_{2.5}$ and CO was decreased by 24.6%, 12.1%, 14.8%~~14.5%~~, 7.3%~~6.9%~~ and 7.2%, respectively. Consequently, stringent emission control measures can reduce the concentrations of air pollutants in short term, and emission reduction is the dominant factor of the air quality improvement during the YOG, which has set up a good example in air protection for important social events.

KEY WORDS: Youth Olympic Games; Emission reduction; Meteorological conditions; WRF/CMAQ; Nanjing

1 Introduction

As located in the economically developed Yangtze River Delta (YRD) region of China, Nanjing successfully hosted the second Youth Olympic Games (YOG) during 16 - 28 Aug~~ust~~., 2014. Nanjing is a highly urbanized city and its GDP ranked the 12th of all the cities in China by 2013 (National Bureau of Statistics of China, 2014). Due to fast urbanization and industrialization, heavy motor vehicles and construction dust, Nanjing has long been suffered from air pollution (~~Wei et al., 2009; Zhang et al., 2009; Gao et al., 2012;~~ Dong et al., 2013; Chen et al., 2015).

In order to realize the promise of "Green YOG", the local government had taken a series of measures to reduce emissions of air pollutants. The preparatory work started from 1 Jul., 2014.~~Preparatory work were carried out since 1 July, 2014.~~ Besides, the local government performed the stringent environmental quality assurance work plan from 1 Aug. (National Bureau of Statistics of China, 2014)~~strengthened efforts were performed from 1 August. What's more, an air pollution joint prevention group including Nanjing and 22 surrounding cities was established to ensure the air quality of August in Nanjing (Ministry of Environmental Protection of the People's Republic of China, 2014)~~. The controlled emission~~ sourcess~~ include 5 major categories: industry, power plants, traffic, VOC product-related sources and others. Some local petrochemical, chemical and steel industries were forced to limit or halt the production~~,~~. C~~c~~oal-combustion enterprises were required to use high-quality coals with low sulfur content and ash content.~~;~~ And heavy pollution vehicles called “yellow label buses” were prohibited in Nanjing during 10-28 Aug~~ust~~.~~,~~ Oil loading and ~~transfer benefits of public transportation were offered,~~ unloading operations were strictly controlled. Construction process was forced to stop.

It is well known that air quality can be affected by both meteorological factors and pollutant emissions. Many cases verified that both emission abatement efforts and weather conditions do influence the air quality improvement. Emission control has~~ve~~ been taken in many social events, like Beijing Olympic Games in 2008 and Shanghai Expo in 2010. Xing~~Jia~~ et al. (2011) suggested that emission controls benefit for~~ all~~ pollutants reduction~~s~~, but meteorological effects can be either ways at different locations. Cermak and Knutti (2009), Wang et al. (2009b, 2010) and Xing et al. (2011) reported that typical meteorological conditions accounted more for air improvement during 2008 Beijing Olympics than emission reductions. Zhou et al. (2010) concluded that transportation control measures resulted in a reduction of 44.5% and 49.0% in daily CO and NO_x emission from motor vehicles during the 2008 Olympics. Cai et al. (2011) and Wang et al. (2009a) also studied the transportation controls on improving air quality during Beijing Olympic Games. Okuda et al. (2011) argued that sources control during Beijing Olympics significantly reduced PM_{10}, NO_2 and SO_2, but did not as effectively reduce $PM_{2.5}$. Streets et al. (2007) proposed that local sources controlling is inadequate for heavily populated, urbanized, and industrialized city, regional air quality management is in urgent need. Lin et al. (2013) applied monitoring data to analyze the weather impacts on air quality of the World Expo in YRD and concluded that high frequency of marine winds during the Expo had a positive effect on the air quality of coastal cities, but a negative effect on some inland cities in YRD. Satellite data reflected that the tropospheric NO_2 column, aerosol optical thickness (AOT), and CO concentration dropped by 8%, 14% and 12%, respectively over Shanghai during the Expo period, compared to the past three years (Hao et al., 2011). ~~Huang et al. (2013) and Chen et al. (2013) analyzed the weather impacts on air quality of the World Expo in Shanghai and concluded that weather conditions were important in affecting air quality.~~ Liu et al. (2013) compared the contributions of long-term and short-term emission control via CMAQ simulation and compared their effects on air quality in Guangzhou during the Asian Games. Xu et al. (2013) concluded that $PM_{2.5}$ was mainly emitted from anthropogenic sources other than biogenic sources and indicated that cut down anthropogenic emissions could increase $PM_{2.5}$ effectively. Dong et al. (2013) found that independent NO_x emission reduction would strengthen O_3 as a side effect in YRD. Chen et al. (2015, 2017) studied the source apportionment of size-fractionated particles in Nanjing, and found that construction dust contributes the most in coarse particles, and fugitive and construction dust decreased significantly in YOG.

There have been some studies on air quality during the 2nd YOG (Ding et al., 2015; Chen et al., 2017; Zhou et al. 2017~~Zhao et al., 2015; Wang et al., 2015; Mu et al., 2016; Li et al., 2016~~), but few work focused on the relative contributions of meteorology and control efforts. This study takes the air quality monitoring data and applies WRF/CMAQ model to estimate the effect of meteorological factors and emission reduction on air quality of Nanjing during YOG. Data and model descriptions as well as simulation scenarios are described in Section 2. Section 3 examines the characteristics of six major air pollutants (SO_2, NO_2, PM_{10}, $PM_{2.5}$, CO and O_3) and compares their concentrations during YOG with those a year ago and the ~~earlier~~months without emission reduction ~~month~~ (Jul~~y~~. and Sept., 2014). Besides, this section discusses the separate effect of weather conditions and emission abatement qualitatively and quantitatively based on the simulation results. Section 4 summaries the main conclusions, emphasizes the dominant factor of the air quality promotion during YOG, and provides some advice for ensuring pleasant future air quality.

2 Methodology

2.1 Data description

Hourly observed air quality data during Jul~~y~~.- Sept~~ember~~. 2014 and Aug~~ust~~. 2013 of two representative stations was from Nanjing Environmental Monitoring Center (http://222.190.111.117:8023/). Both of the two stations are state controlling air sampling sites. The data quality assurance and quality control procedures for monitoring strictly follow the national standards (State Environmental Protection Administration of China, 2006). Caochangmen (CCM) Station (118.75° E, 32.06° N) locates in Gulou District, the city center of Nanjing. Gulou District is the center of economy, politics, culture and education in Nanjing. Here gathers many East China's high-end industrial and corporate headquarters. Besides, over 90% provincial authorities, more than 20 colleges and universities, and more than 120 research institutes situate in Gulou District. It's the most populated area in Nanjing, with lively commercial hub and heavy traffic. Thus, CCM station was chosen to represent the urban status of Nanjing. The other ~~station is~~site calls Xianlin (XL) Station (118.92° E, 32.11° N)~~. XL station~~, which locates in Qixia District, the suburb of Nanjing. Compared to Gulou District, Qixia District is much more sparsely populated. And there is no traffic congestion problem in Qixia District. Thus, XL station was chosen to represent the suburban status of Nanjing. ~~The names of the two sites are Caochangmen (CCM) Station (118.75° E, 32.06° N) and Xianlin (XL) Station (118.92° E, 32.11° N), which are the two of national air sampling sites, representing urban and suburban status in Nanjing.~~

2.2 Model description

The integrated modeling system WRF/CMAQ was employed in this research. Community Multiscale Air Quality (CMAQ) is a third-generation regional air quality model developed by the Environmental Protection Agency of USA (USEPA). It incorporates a set of up-to-date compatible modules and control equations for the atmosphere, and can fully consider atmospheric complicated physical and chemical processes and the relative contribution of different species (Byun and Schere, 2006; Foley et al., 2010). Many applications have proven that CMAQ is a reliable tool in simulating air quality from city scale to mesoscale (Xing et al., 2011; Dong et al., 2013; Liu et al., 2013; Xu et al. 2013; Shu et al., 2016). Community Multiscale Air Quality (CMAQ v4.7.1, Binkowski and Roselle, 2003) model includes the 2005 Carbon Bond gas-phase mechanism (CB05) (Yarwood et al., 2005) and the fourth-generation CMAQ aerosol module (AERO4) (Byun and Schere, 2006) ~~aerosol~~

module,. And it was applied to simulate the pollutant distribution over Nanjing in this paper.and Weather Research and Forecasting (WRF) is a new generation of mesoscale weather forecast model and assimilation system, developed by the National Center for Atmospheric Research (NCAR). WRFIt has been widely applied in China and shows a good performance in all kinds of weather forecasts (Jiang et al., 2008, 2012; Xu et al.,2013; Liao et al., 2014, 2015; Xie et al., 2014, 2016; Li et al., 2016; Shu et al., 2016). Weather Research and Forecasting (WRF v3.2.1, (Skamarocket al., 2008) model was run to provide meteorology fields for CMAQ. Four nested domains were set for both models, with horizontal resolutions of 81km, 27km, 9km, 3km, with the innermost domain covering Nanjing (Fig.1). In domain4, the 9 state controlling air sampling sites in Nanjing were chosen to represent the whole Nanjing in conformity with the observation (See Fig.1, Table1). For all domains, 23 vertical sigma layer from the surface to the top pressure of 100 hpa was set, with about 10 layers in the planetary boundary layer. The detail dynamic parameterization in WRF as well as the physical and chemical schemes of CMAQ applied in this research were the same as those in the research of Shu et al. (2016) and were proven to have good simulation performance (Shu er al., 2016). As for the innermost domain, Nanjing Municipal Environmental Protection Bureau chooses the local 9 state controlling air sampling sites (See Fig.1, Table1) to represent the whole Nanjing city. In conformity with this, we chose the 9 state controlling air sampling sites in domain4 were chosen to represent the whole Nanjing while analyzing model simulation impacts.

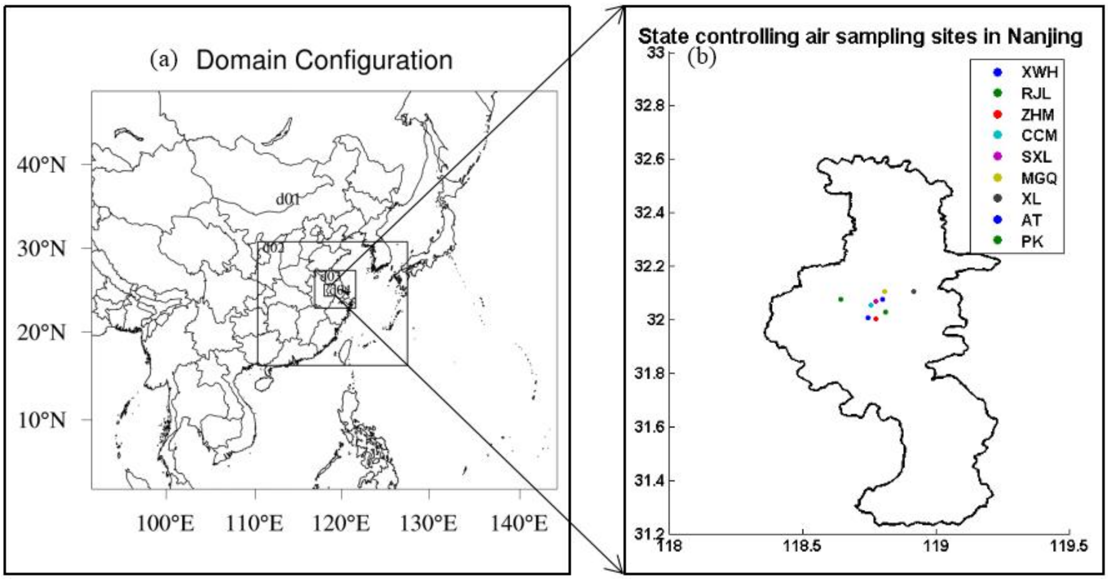


Fig.1. Modeling ~~areas~~domains and state controlling air sampling sites in Nanjing. ((a) The four nested modeling domains at 81km (D01: East Asia), 27km (D02: East China), 9km (D03: Yangtze River Delta), and 3km (D04: Nanjing), (b) Locations of 9 state controlling air sampling sites in Nanjing).

Table 1

The air sampling sites in Nanjing

Air sampling sites	Abbreviations	Location
Xuanwuhu Station	XWH	32.08° N, 118.80° E
Ruijinlu Station	RJL	32.03° N, 118.82° E
Zhonghuamen Station	ZHM	32.00° N, 118.76° E
Caochangmen Station	CCM	32.06° N, 118.75° E
Shanxilu Station	SXL	32.07° N, 118.77° E
Maigaoqiao Station	MGQ	32.11° N, 118.81° E
Xianlin Station	XL	32.11° N, 118.92° E
Aoti Station	AT	32.01° N, 118.74° E
Pukou Station	PK	32.07° N, 118.64° E

2.3 Emissions and simulation scenarios

In this study, Multi-resolution Emission Inventory for China (MEIC v1.2, http://www.meicmodel.org/) with a resolution of 0.25° × 0.25° was employed to provide the anthropogenic emissions for species including SO_2, NO_x, CO, NMVOC, NH_3, CO_2, $PM_{2.5}$, PM_{10}, BC, and OC, form 4 sectors: industry, power plants, transportation, and residential. What's more, the innermost domain used the local emission inventory before and after emission reduction, with a horizontal resolution of 3km × 3km.

The innermost domain emission inventory before emission control was based on the local emissions in 2012 (basic emission inventory), and the emissions outside Nanjing city were from MEIC. Besides, the basic assumption was that emissions under control were less than the emissions before control inside Nanjing city, and the emissions outside Nanjing city were set the same before and after emission control in Nanjing. According to the local emission control program, we adjusted the basic emission inventory and got the emission inventory under emission control. 5 major categories: industry, power plants, traffic, VOC product-related sources and others were in the emission sources control list. In Aug. 2014, all coal-combustion enterprises must use high-quality coals with low sulfur content less than 0.5% and ash content less than 13%. Besides, the local government ordered over 100 local petrochemical, chemical and steel enterprises to cut or halt their production during Aug. 2014. Moreover, heavy pollution vehicles were prohibited in Nanjing during 10-28 Aug. 2014 to reduce traffic pollution. To reduce emissions of volatile organic compounds, loading and unloading oil operations were prohibited at the docks in Nanjing section of Yangtze River. What's more, local construction work was halted during Aug. 2014. Over 100 local petrochemical, chemical and steel enterprises were forced to cut or halt their production during Aug. 2014. Heavy pollution vehicles called "yellow label buses" were prohibited in Nanjing during 10-28 Aug.. To reduce emissions of volatile organic compounds, loading and unloading oil operations were prohibited at the docks in Nanjing section of Yangtze River. With these efforts, the emission sources would be cut by 25.0% for SO_2, 15.0% for NO_x, 42.8% for PM_{10}, 36.2% for $PM_{2.5}$, and 20.0% for CO. The spatial distributions of emission reduction were showed in Fig.2. For SO_2, NO_x, PM_{10} and $PM_{2.5}$, the emission reduction area centered in the middle of Nanjing city. And for CO, the emission reduction centered in several points.

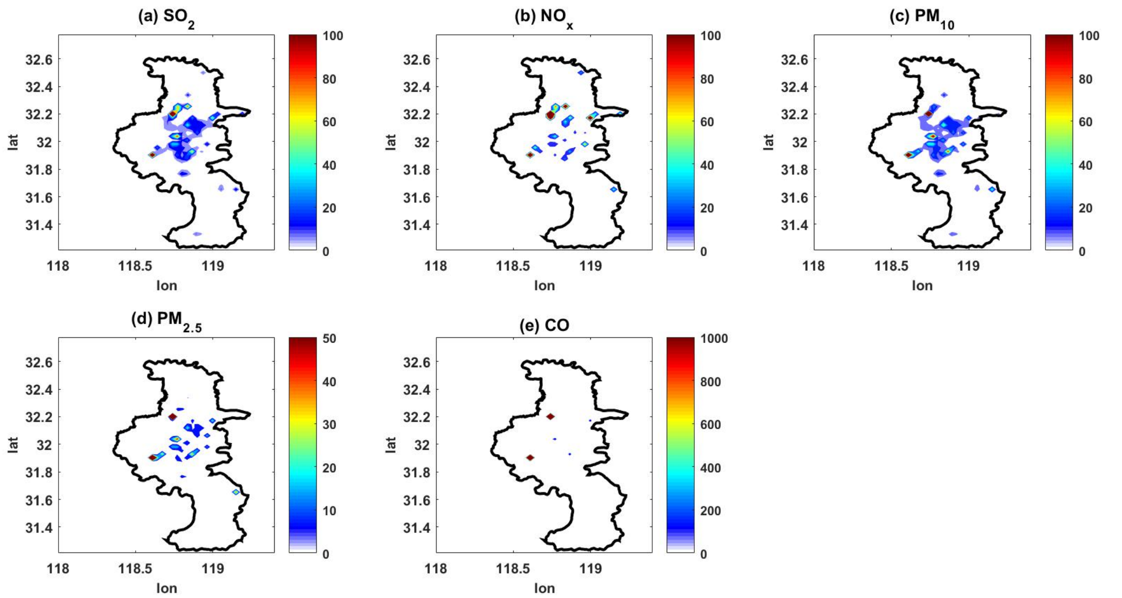


Fig.2. Emission reduction in domain4 ((a) SO_2, (b) NO_X, (c) PM_{10}, (d) $PM_{2.5}$, (e) CO (unit: t/month)).

The simulated period was from Jul. 27 to Sept. 1 (China standard time, CST), but only the holding month (1 Aug.~~-1~~ to 31 Aug.~~-31~~) was focused on. In order to better understand the influence of meteorological factors~~meteorology~~ and emission abatement, three experiments were carried out. Exp.1 used the weather conditions during Aug~~ust~~. 2014 (CST) and the emission inventory after reduction while Exp.2 used the same weather conditions with the emission inventory before reduction. Exp.3 had the same inventory as Exp.2 but used the weather conditions during Aug~~ust~~. 2013 (CST). Besides, Exp.2 acted as the control experiment. What's more, Exp.1 and Exp.2 were set to study the influence of emission reduction on pollutants only. Similarly, Exp.2 and Exp.3 were conducted to understand the impact of meteorology on air quality ~~contaminants~~ only.

3 Results and discussion

3.1 Observed a~~A~~ir quality during YOG

In the most strictly emission control month Aug~~ust~~ .2014, emission sources including~~over 30 kinds of pollutant emissions~~ 5 major categories were reduced, and ~~among which, the total reduction percent in Nanjing was 22.1% for SO_2, 12.5% for~~

~~NO_x, 15.0% for CO, 9.2% for VOCs, 38.1% for PM_{10} and 21.4% for $PM_{2.5}$.~~

~~With the control measures,~~ the air quality had great promotion ~~in August. 2014~~ compared to Aug~~ust~~. 2013.

Firstly, it was good during the Games in accordance with China's National Ambient Air Quality Standards (NAAQS) (Ministry of Environmental Protection of the People's Republic of China, 2012) (Fig.3~~2~~, Fig.4~~3~~). The hourly mean pollutant concentration of the two sites during Aug. 2014 is 11.6 μg/m^3 for SO_2, 34.0 μg/m^3 for NO_2, 57.8 μg/m^3 for PM_{10}, 39.4 μg/m^3 for $PM_{2.5}$, 0.9 mg/m^3 for CO, and 38.8 μg/m^3 for O_3. Secondly, as showed in Table 2 and Table 3, the mean concentration of the six major species (SO_2, NO_2, PM_{10}, $PM_{2.5}$, CO and O_3) dropped by 64.7% for SO_2, 29.8% for PM_{10}, 9.8% for $PM_{2.5}$, 8.9% for CO and 31.7% for O_3 at CCM station, while 50.0% for SO_2, 18.6% for NO_2, 32.8% for PM_{10}, 4.1% for $PM_{2.5}$, and 31.7% for O_3 at XL station. Besides, the smaller standard deviation (std) of SO_2, NO_2, CO and O_3 revealed that concentrations of these air pollutants varied more steadily in Aug~~ust~~. 2014. However, the drop of pollutant concentration could be caused mainly by meteorology conditions or emission reductions. And we will discuss the reason based on model simulations in Section 3.2 and Section 3.3.

~~These results indicated that emission reductions did help the alleviation of air pollution and cut down the possibility of extreme events occurrence.~~

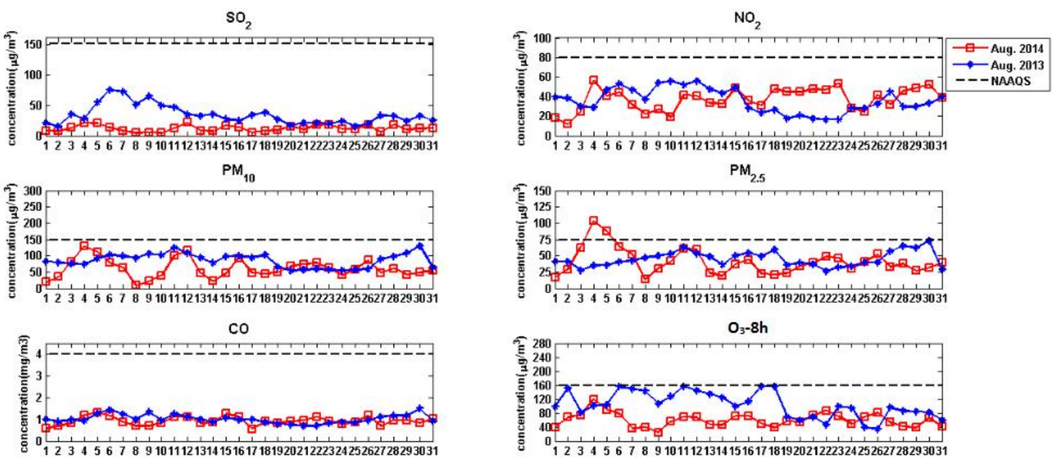


Fig.~~2~~3. Day-to-day variations in SO_2, NO_2, PM_{10}, $PM_{2.5}$, CO and O_3-8h at CCM station in Aug~~ust~~. 2013 and Aug~~ust~~. 2014 (CST). Observed data in Aug~~ust~~. 2013 are indicated in blue. Observed data in

Aug~~ust~~ .2014 are indicated in red. NAAQS are indicated in black dotted line.

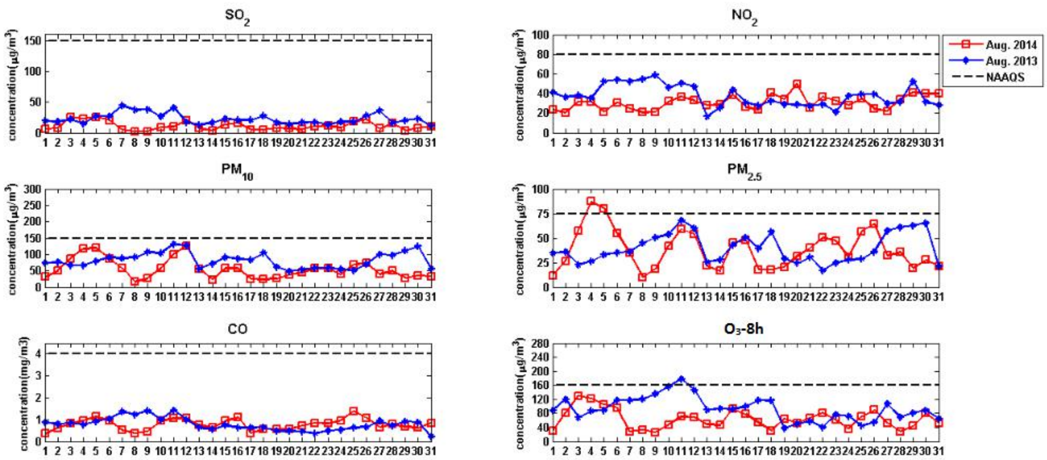


Fig.~~3~~4. Day-to-day variations in SO_2, NO_2, PM_{10}, $PM_{2.5}$, CO and O_3-8h at XL station in Aug~~ust~~. 2013 and Aug~~ust~~. 2014 (CST). Observed data in Aug~~ust~~. 2013 are indicated in blue. Observed data in Aug~~ust~~. 2014 are indicated in red. NAAQS are indicated in black dotted line.

Table 2

Statistical analysis of hourly data in Aug~~ust~~. 2013 and Aug~~ust~~. 2014 at CCM station (The unit is μg/m^3 except CO (mg/m^3))

species	time	max	min	mean	median	std	Δ
SO_2	Aug. 2013	169.0	1.0	33.7	27.0	23.7	
	Aug. 2014	72.0	2.0	11.9	10.0	7.8	-64.7%
NO_2	Aug. 2013	111.0	1.0	35.4	32.0	19.4	
	Aug. 2014	110.0	1.0	37.3	35.0	18.6	5.0%
PM_{10}	Aug. 2013	213.0	19.0	86.0	84.0	29.5	
	Aug. 2014	198.0	6.0	60.4	54.0	36.6	-29.8%
$PM_{2.5}$	Aug. 2013	123.0	10.0	45.2	43.5	16.2	
	Aug. 2014	165.0	3.0	40.7	36.0	23.8	-9.8%
CO	Aug. 2013	3.1	0.4	1.0	0.9	0.4	
	Aug. 2014	2.2	0.3	0.9	0.9	0.3	-8.9%
O_3	Aug. 2013	198.0	1.0	56.9	42.0	46.2	
	Aug. 2014	150.0	9.0	38.9	34.0	22.6	-31.7%

Δ : the change percentage of species in Aug~~ust~~. 2014 based on Aug~~ust~~. 2013.

Table 3

Statistical analysis of hourly data in Aug~~ust~~. 2013 and Aug~~ust~~. 2014 at XL station (The unit is μg/m^3 except CO (mg/m^3))

species	time	max	min	mean	median	std	Δ
SO_2	Aug. 2013	139.0	0.0	22.8	19.0	16.1	

	Aug. 2014	71.0	1.0	11.4	8.0	10.4	-50.0%
NO_2	Aug. 2013	129.0	0.0	37.7	32.0	21.7	
	Aug. 2014	95.0	7.0	30.7	27.0	15.0	-18.6%
PM_{10}	Aug. 2013	215.0	0.0	82.1	79.0	32.4	
	Aug. 2014	196.0	6.0	55.2	47.0	35.9	-32.8%
$PM_{2.5}$	Aug. 2013	122.0	0.0	39.7	37.5	18.9	
	Aug. 2014	157.0	3.0	38.0	34.0	24.1	-4.1%
CO	Aug. 2013	3.2	0.0	0.8	0.7	0.4	
	Aug. 2014	2.0	0.3	0.8	0.7	0.3	<0.1%
O_3	Aug. 2013	193.0	0.0	56.6	44.0	37.5	
	Aug. 2014	148.0	2.0	38.7	32.0	28.3	-31.7%

Δ : the change percentage of species in Aug~~ust~~. 2014 based on Aug~~ust~~. 2013.

Analogously, compared the observational data in Aug~~ust~~. 2014 with that in Jul~~y~~. and Sept~~ember~~. 2014 (the months before and after the most aggressive abatement), the concentrations of most species decreased obviously~~most species had a good reflection in August~~. As presented in Fig.~~4~~5 and Fig.~~5~~6, without abatement, NO_2, PM_{10}, $PM_{2.5}$ and O_3 were likely to exceed NAAQS, especially $PM_{2.5}$ and O_3. As shown in Table 4 and Table5, compared with Jul. 2014, the concentration of NO_2, PM_{10}, $PM_{2.5}$, CO and O_3 dropped by 0.7%, 31.8%, 33.7%, 1.1%, and 52.8%, respectively at CCM station in Aug. 2014, while the concentration of SO_2, NO_2, PM_{10}, $PM_{2.5}$, CO and O_3 decreased by 15.8%, 39.6%, 34.6%, 7.1%, and 50.7%, respectively at XL station in Aug. 2014. Without emission control, the concentration of air pollutants rebounded in Sept. 2014. Compared with Aug., the concentration of SO_2, NO_2, PM_{10}, $PM_{2.5}$ and O_3 increased by 37.4%, 19.8%, 37.6%, 22.3%, and 47.2%, respectively at CCM station in Sept. 2014 (Table 4), while the concentration of SO_2, NO_2, PM_{10}, $PM_{2.5}$, CO and O_3 increased by 24.6%, 21.8%, 28.7%, 17.7%, 4.9%, and 39.9%, respectively at XL station in Sept. 2014 (Table 5). ~~And the change percentage of species (SO_2, NO_2, PM_{10},$PM_{2.5}$,CO and O_3) in August based on July was 5.1%, -0.7%, -31.8%, -33.7%, -1.1%, and -52.8%, respectively at CCM station (Table 4), while that was -21.2%, -15.8%, -39.6%, -34.6%, -7.1%, and -50.7%, respectively at XL station (Table 5). Compared the data in August to September, the change percentage of species (SO_2, NO_2, PM_{10}, $PM_{2.5}$, CO and O_3) was -37.4%, 19.8%, -37.6%, -22.3%, 21.1%, and -47.2%, respectively at~~

~~CCM station (Table 4), while that was -24.6%, -21.8%, -28.7%, -17.7%, -4.9%, and -39.9%, respectively at XL station (Table 5). That is, the pollutant concentrations declined with emission control, but rebounded after releasing control.~~ Besides, for most species, the standard deviation was the lowest in Aug~~ust~~., which meant that the potential of extreme events was the least in Aug~~ust~~.. Assume that the weather conditions in Jul., Aug., Sept., 2014 were similar, it can be estimated that~~then~~ emission sources could be the major impact factor of ~~pollutant~~explaining the concentration changes during the three months. These results proved that concentrations of most species decreased and had less potential in extreme events after aggressive emission abatement. However, they c~~w~~ould rebound without emission control. Besides, Section 3.3 would further discuss the change of pollutant concentration with and without emission reduction based on model simulation.

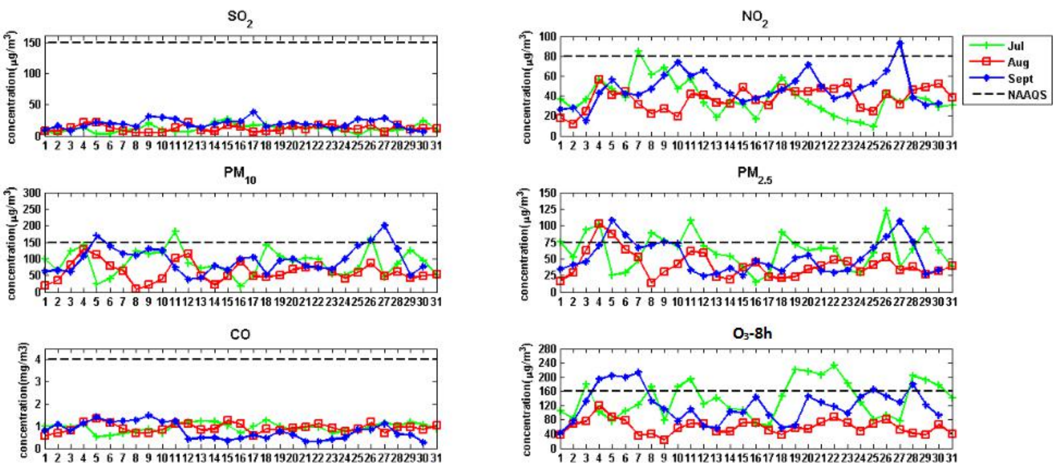


Fig.~~4~~5. Day-to-day variations in SO_2, NO_2, PM_{10}, $PM_{2.5}$, CO and O_3-8h at CCM station in Jul.~~y~~, Aug~~ust~~. and Sept~~ember~~. 2014 (CST). Observed data in Jul~~y~~., Aug~~ust~~. and Sept~~ember~~. 2014 are indicated in green, red and blue, respectively. NAAQS are indicated in black dotted line.

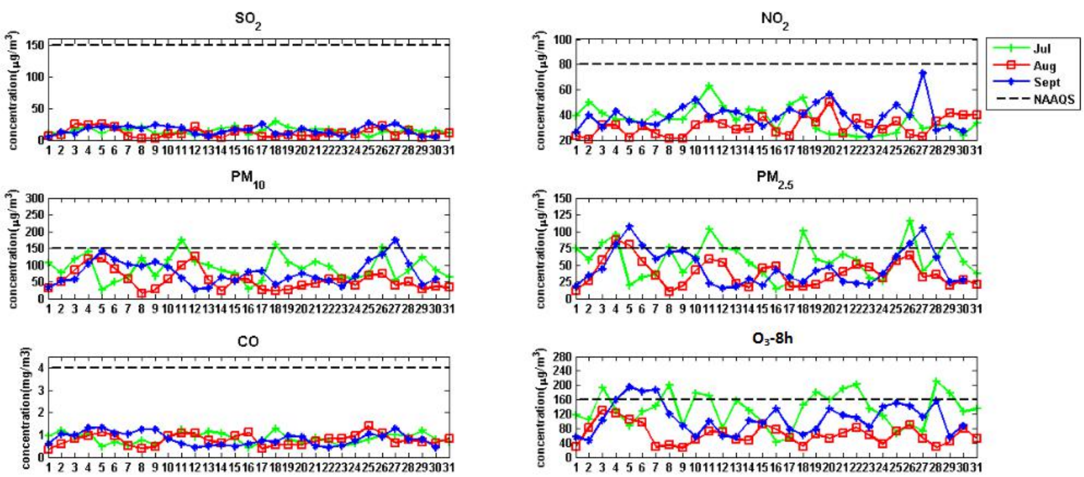


Fig.~~5~~6. Day-to-day variations in SO_2, NO_2, PM_{10}, $PM_{2.5}$, CO and O_3-8h at XL station in Jul~~y~~., Aug~~ust~~. and Sept~~ember~~. 2014 (CST). Observed data in Jul~~y~~., Aug~~ust~~. and Sept~~ember~~. 2014 are indicated in green, red and blue, respectively. NAAQS are indicated in black dotted line.

Table 4

Statistical analysis of hourly data in Jul~~y~~. - Sept~~ember~~. 2014 at CCM station (The unit is μg/m^3 except CO (mg/m^3))

species	month	max	min	mean	median	std	Δa	Δb
	Jul. 2014	83.0	1.0	11.3	9.0	9.8		
SO_2	Aug. 2014	72.0	2.0	11.9	10.0	7.8	5.1%	-37.4%
	Sept. 2014	70.0	4.0	19.0	18.0	9.9		
	Jul.-Sept. 2014	83.0	1.0	14.0	12.0	9.8		
	Jul. 2014	161.0	1.0	37.5	32.0	28.3		
NO_2	Aug. 2014	110.0	1.0	37.3	35.0	18.6	-0.7%	-19.8%
	Sept. 2014	151.0	8.0	46.5	42.0	24.5		
	Jul.-Sept. 2014	161.0	1.0	40.2	37.0	24.4		
	Jul. 2014	255.0	6.0	88.5	88.0	50.7		
PM_{10}	Aug. 2014	198.0	6.0	60.4	54.0	36.6	-31.8%	-37.6%
	Sept. 2014	243.0	6.0	96.7	90.0	45.8		
	Jul.-Sept. 2014	255.0	6.0	81.7	76.0	47.4		
	Jul. 2014	171.0	1.0	61.5	58.0	33.9		
$PM_{2.5}$	Aug. 2014	165.0	3.0	40.7	36.0	23.8	-33.7%	-22.3%
	Sept. 2014	143.0	3.0	52.4	46.0	27.2		
	Jul.-Sept. 2014	171.0	1.0	51.5	45.0	29.9		
	Jul. 2014	2.7	0.2	0.9	0.9	0.3		
CO	Aug. 2014	2.2	0.3	0.9	0.9	0.3	-1.1%	21.1%
	Sept. 2014	2.1	0.1	0.8	0.7	0.4		
	Jul.-Sept. 2014	2.7	0.1	0.9	0.8	0.4		
	Jul. 2014	281.0	4.0	82.4	69.0	57.6		

O_3	Aug. 2014	150.0	9.0	38.9	34.0	22.6	-52.8%	-47.2%
	Sept. 2014	240.0	6.0	73.6	61.0	49.2		
	Jul.-Sept. 2014	281.0	4.0	64.7	51.0	49.3		

Δa: the change percentage of species in Aug~~ust ~~.2014 based on Jul~~y~~. 2014.
Δb: the change percentage of species in Aug~~ust~~. 2014 based on Sept~~ember~~. 2014.

Table 5

Statistical analysis of hourly data in Jul~~y~~. - Sept~~ember ~~.2014 at XL station (The unit is μg/m^3 except CO (mg/m^3))

species	month	max	min	mean	median	std	Δa	Δb
	Jul. 2014	61.0	1.0	14.5	12.0	10.3		
SO_2	Aug. 2014	71.0	1.0	11.4	8.0	10.4	-21.2%	-24.6%
	Sept. 2014	75.0	1.0	15.1	14.0	10.3		
	Jul.-Sept. 2014	75.0	1.0	13.7	11.0	10.4		
	Jul. 2014	123.0	9.0	36.4	33.0	18.9		
NO_2	Aug. 2014	95.0	7.0	30.7	27.0	15.0	-15.8%	-21.8%
	Sept. 2014	127.0	11.0	39.2	36.0	18.7		
	Jul.-Sept. 2014	127.0	7.0	35.4	32.0	18.0		
	Jul. 2014	300.0	4.0	91.3	85.0	48.9		
PM_{10}	Aug. 2014	196.0	6.0	55.2	47.0	35.9	-39.6%	-28.7%
	Sept. 2014	226.0	9.0	77.3	70.0	40.3		
	Jul.-Sept. 2014	300.0	4.0	74.5	64.0	44.6		
	Jul. 2014	158.0	2.0	58.2	51.0	34.8		
$PM_{2.5}$	Aug. 2014	157.0	3.0	38.0	34.0	24.1	-34.6%	-17.7%
	Sept. 2014	144.0	3.0	46.2	38.0	29.0		
	Jul.-Sept. 2014	158.0	2.0	47.4	40.5	30.7		
	Jul. 2014	2.0	0.3	0.8	0.8	0.4		
CO	Aug. 2014	2.0	0.3	0.8	0.7	0.3	-7.1%	-4.9%
	Sept. 2014	2.8	0.3	0.8	0.7	0.4		
	Jul.-Sept. 2014	2.8	0.3	0.8	0.7	0.4		
	Jul. 2014	238.0	2.0	78.4	67.0	55.6		
O_3	Aug. 2014	148.0	2.0	38.7	32.0	28.3	-50.7%	-39.9%
	Sept. 2014	226.0	2.0	64.4	54.0	46.4		
	Jul.-Sept. 2014	238.0	2.0	60.3	48.0	47.7		

3.2 Simulated i~~I~~mpact of meteorological conditions

In this paper, the model configurations were the same as those set by Shu et al. (2016), who has~~. Shu et al. (2016) have~~ evaluated the model performance of WRF/CMAQ and proved the model's reliability in simulating air quality in Nanjing.~~-~~

So, we will no longer validate the model performance here.

Meteorology is an important impact factor on air quality. Good diffusion conditions can alleviate air pollution in the short term (Cermak and Knutti, 2009; Wang et al., 2009b). In this premise, if two experiments (Exp.2 and Exp.3) use the same emission inventory but different weather conditions, it can be concluded that the higher concentrations may result fromthen we can say the experiment resulting in higher pollutant concentrations has much more poor meteorology conditions. According to model simulation,However, the simulated meteorological condition in August, 2014 (CST) was not as good as that in 2013, with more overcast days, lower temperature and weaker winds, especially during the YOG (See Fig 6), which was consistent with the observations (Mu et al., 2015). Consequently, Exp.2 exhibitedresulted in higher pollutant concentrations for all species as shown in Fig.7. For SO_2, NO_2, PM_{10}, $PM_{2.5}$, CO, and O_3, their concentrations were increased by 17.5%, 16.9%, 19.0%, 19.5%, 7.8% and 0.8% during August. 2014 compared to August. 2013. That is to say, the diffusion conditions in Aug. 2014 were worse than those in Aug. 2013. The simulated hourly mean 10-m wind speed in Nanjing was larger in Aug. 2013, especially in 16-28 Aug., and it was 1.5 m/s larger than that of 16-28 Aug., 2014 (Fig.8). Also, the simulated 2-m temperature was higher in Aug. 2013, especially in 16-28 Aug., and it was 2.0 K larger than that of 16-28 Aug., 2014 (Fig.8). Besides, the simulated planetary boundary layer height (PBLH) was higher in Aug. 2013, especially in 16-28 Aug., and it was 27.5 m higher than that of 16-28 Aug., 2014 (Fig.8). Larger wind speed and higher PBLH benefited the diffusion. Warming on the ground surface was conductive to the promotion of convective instability and was also good for the dilution and diffusion of pollutant. Thus, the simulation meteorological conditions in Aug. 2013 were better than those in Aug. 2014. Rather worse meteorological conditions in Aug. 2014 implied that abatement controls might play a decisive role in improving air quality in YOG compared with the same period in 2013.

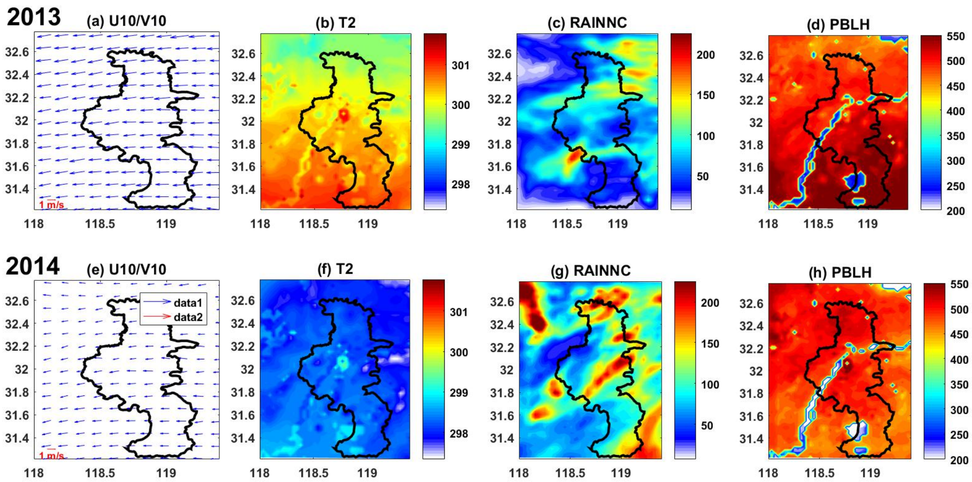
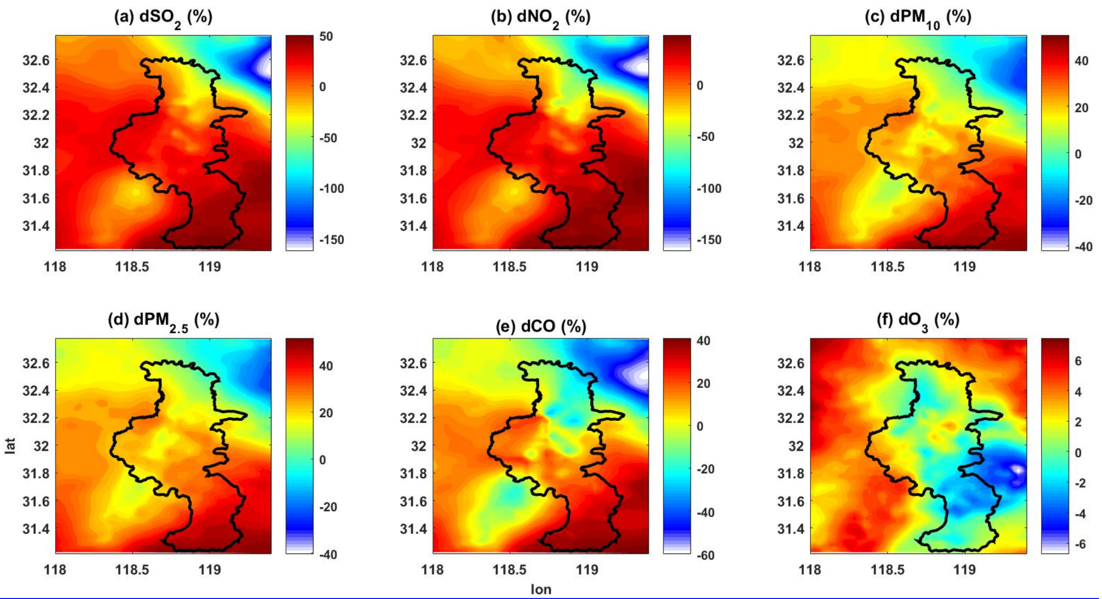


Fig. 6. Simulated meteorological conditions during the YOG. ((a) Wind at 10m in 2013 (unit: m/s), (b) Temperature at 2m in 2013 (unit: K), (c) Accumulated total grid scale precipitation in 2013 (unit: mm), (d) PBL height in 2013 (unit: m), (e) Wind at 10m in 2014 (unit: m/s), (f) Temperature at 2m in 2014 (unit: K), (g) Accumulated total grid scale precipitation in 2014 (unit: mm), (h) PBL height in 2014 (unit: m)).



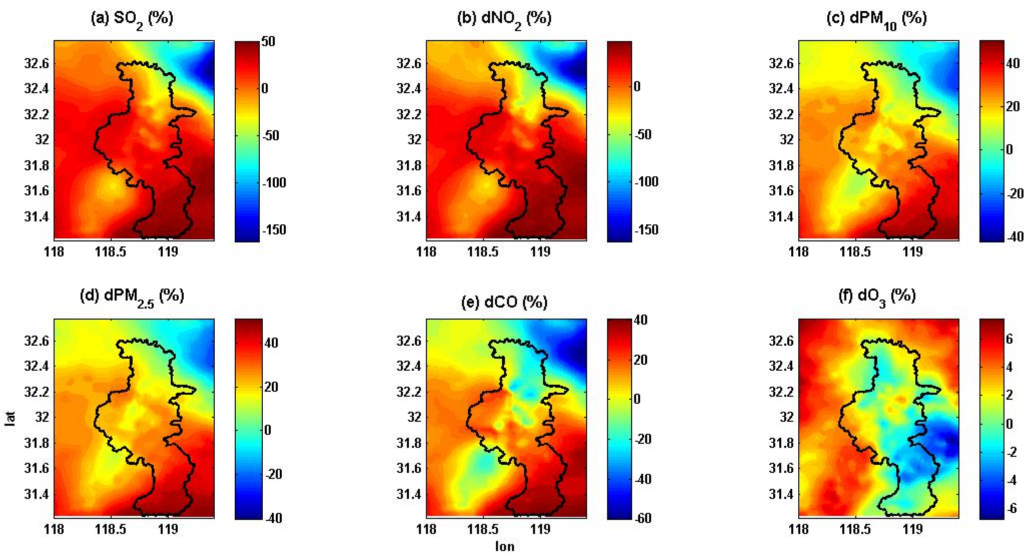


Fig. 7. Influence of meteorology on hourly mean concentrations of pollutants in Aug. 2014 compared with Aug. 2013. (Black thick lines draw the outline of Nanjing. Picture a - f are hourly average values of impact percentage (dspecies (%)= (Exp.2 - Exp.3)/Exp.2 * 100%) of SO_2, NO_2, PM_{10}, $PM_{2.5}$, CO, and O_3, respectively.).

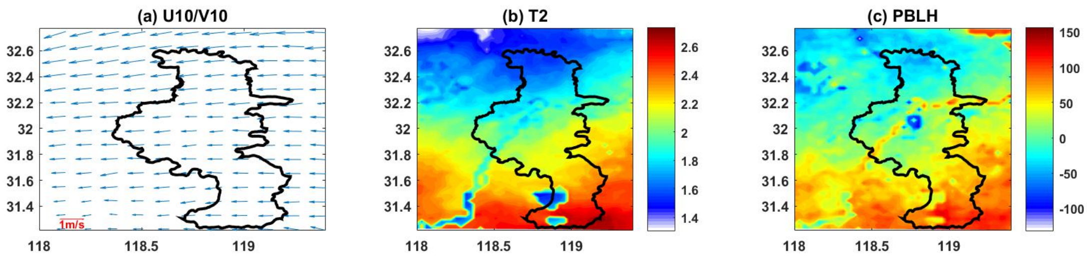
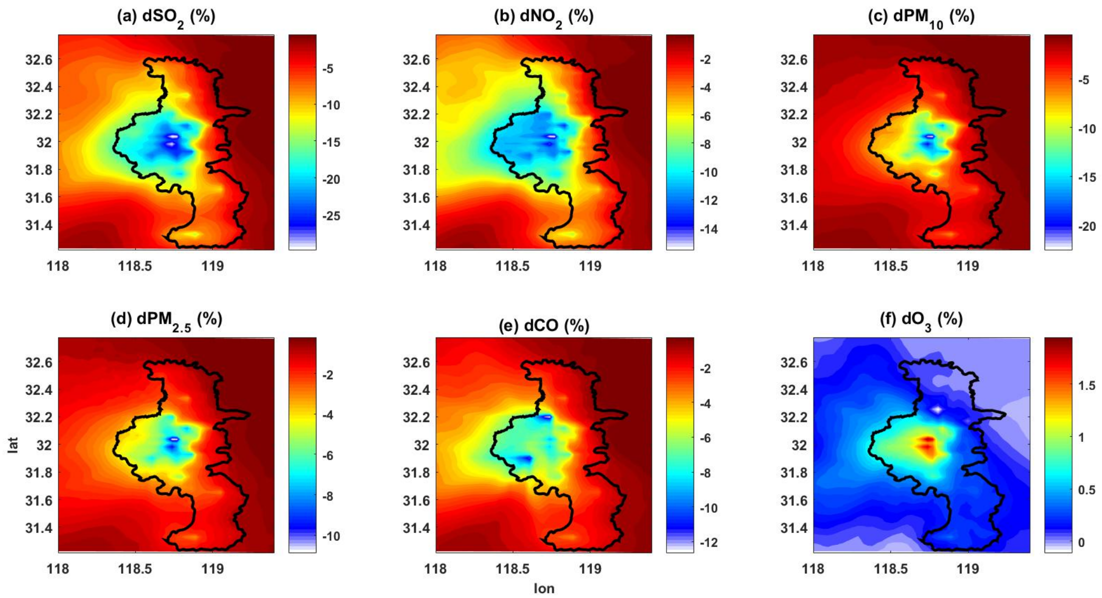


Fig. 8. Bias of simulated hourly mean meteorological conditions during the YOG. (Bias = Meteorological Factors in 16-28 Aug., 2013 - Meteorological Factors in 16-28 Aug., 2014. (a) Bias of Wind at 10m during 16-28 Aug. (unit: m/s), (b) Bias of temperature at 2m during 16-28 Aug. (unit: K), (c) Bias of planetary boundary layer height during 16-28 Aug. (unit: m)).

3.3 Simulated i~~I~~mpact of emission reduction

~~With the strict emission abatement, the amounts of SO_2, NO_x, PM_{10}, $PM_{2.5}$, CO and VOCs were cut down by 9.2% to 38.1%.~~ As for SO_2, NO_2, PM_{10}, $PM_{2.5}$, and CO, the distributions of such short-lived chemical compositions are largely affected by the distributions of their sources and sinks. As seen in Fig.~~8~~9, the simulated spatial distributions of concentration changes were uneven, large variations were found in the west of Nanjing corresponding to the downwind regions of heavy reduction districts (See Fig.2). Besides, impact percentages (dspecies (%) = (Exp.1 - Exp.2)/

Exp.2*100%) of species were negative except O_3, implying that emission regulatory efforts were effective on the other species, but counterproductive~~helped little~~ to O_3. Statistically, the concentrations of SO_2, NO_2, PM_{10}, $PM_{2.5}$, and CO in Nanjing were reduced by 24.6%, 12.1%, 14.8%~~14.5%~~, 7.3%~~6.9%~~ and 7.2% during Aug. 2014~~ the holding month~~. As for O_3,~~ a kind of photochemical products,~~ the variation was positive (1.3%), especially in the downwind area of NO_x heavy reduction region, which might due to the less titration of O_3 by NO_x~~relate to the reduction proportion of NO_x and VOCs~~ (Liu et al., 2013; Dong et al., 2013).



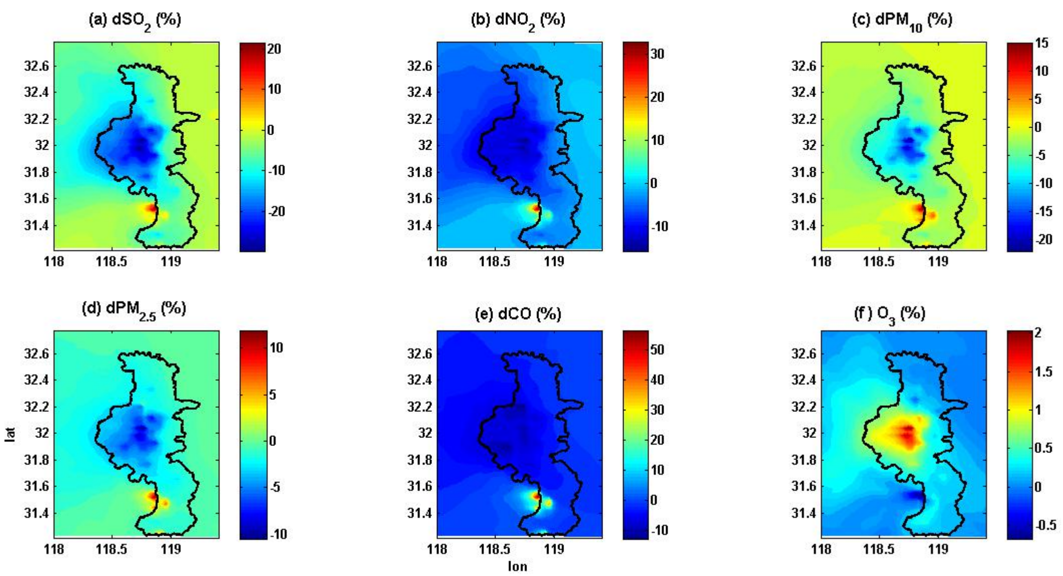
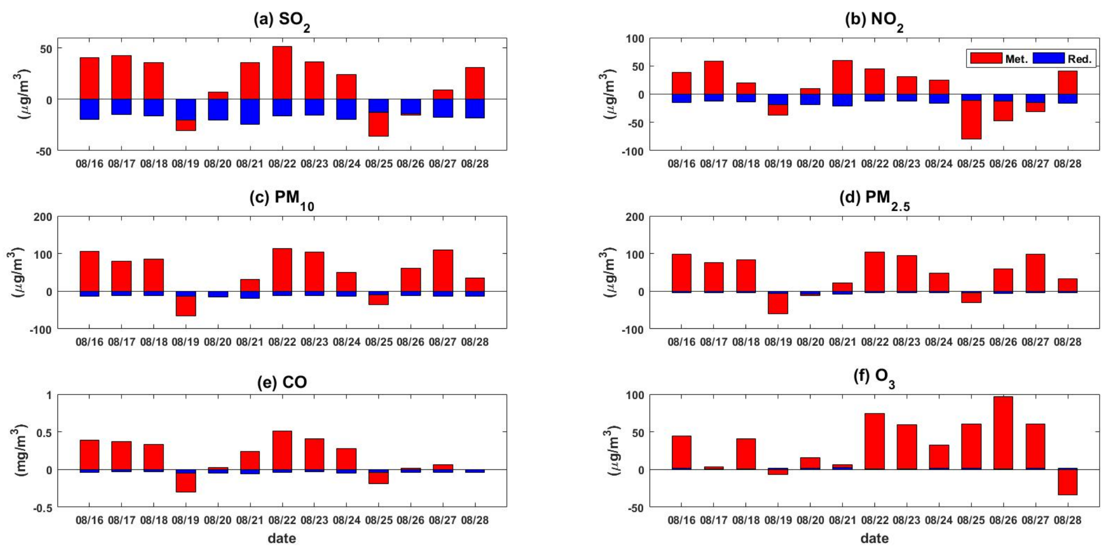


Fig. 98. Influence of emission reduction on hourly mean concentrations of pollutants in Aug. 2014.

(Black thick lines draw the outline of Nanjing. Picture a - f are hourly average values of impact percentage (dspecies (%) = (Exp.1 - Exp.2)/ Exp.2*100%) of SO_2, NO_2, PM_{10}, $PM_{2.5}$, CO and O_3, respectively.).

3.4 Comparison of –simulated meteorological factors and emission reduction

Fig.109 displays the simulated effect of meteorological factors and emission reduction in Nanjing on air quality improvement during YOG (16-28 Aug., 2014). Disadvantage meteorology played a negative role in air quality promotion for all of the six species in most of time, while emission reduction attributed to the decline of SO_2, NO_2, PM_{10}, $PM_{2.5}$, and CO, but caused a slight rise of O_3. This signifies that emission abatement was the crucial factor of the air quality promotion during YOG.



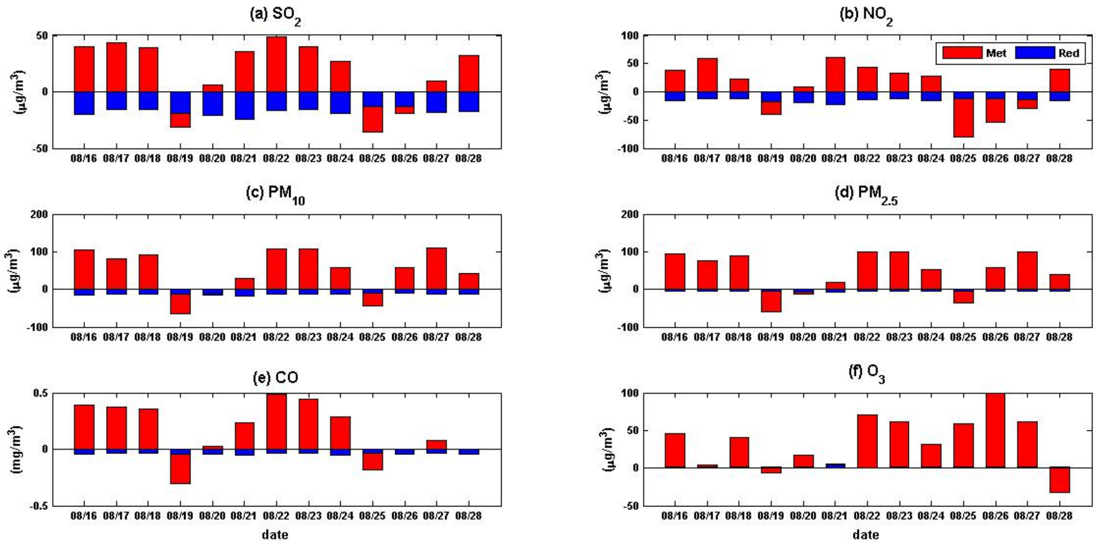


Fig. 10~~9~~. The simulated effect of meteorology and reduction on pollutant concentrations in Nanjing during the YOG (16-28 Aug. , 2014), Met. (Exp.2-Exp.3) represents the effect of meteorology, while Red. (Exp.1-Exp.2) represents the simulated effect of reduction.

Besides, their opposite effects were more apparent at specific sites as listed in Table 6. CCM station represents the urban status and XL station represents the suburban status. Adverse meteorology was found to raise the concentration of the six ~~major~~ pollutants as 17.4% for SO_2, 15.1% for NO_2, 15.9% for PM_{10}, 15.4% for $PM_{2.5}$, 6.4% for CO and 0.9% for O_3 at CCM station, and 14.1% for SO_2, 12.4% for NO_2, 23.2% for PM_{10}, 25.6% for $PM_{2.5}$, 2.3% for CO, and 1.6% for O_3 at XL station. On the contrary, emission abatement~~reduction~~ reduced their levels in most cases, especially in the urban site. It semms that air p~~P~~ollutants reduced with more extent at CCM station. Emission abatement independently led to a 24.3% decrease in SO_2 at CCM station, which was 5.1% higher than that at XL station. Moreover, the cutbacks of NO_2, PM_{10}, $PM_{2.5}$ and CO were 11.7%, ~~13.4~~13.7%, ~~6.4~~6.8% and 7.0%, respectively at CCM station, whose decrease range was larger by ~~0.9~~1.0% to ~~1.5~~2.0% compared with XL station. Though O_3 under emission reduction scenarios resulted in a slightly rise (~~1.1~~0.9% to ~~1.4~~1.3%) at both sites, the effectiveness of emission abatement was remarkable generally.

Table 6

Comparison between the simulated effect of meteorology and emission reduction at CCM and XL station

Species	Met. (CCM)	Red. (CCM)	Met. (XL)	Red. (XL)
SO_2	17.4%	-24.3%	14.1%	-19.2%
NO_2	15.1%	-11.7%	12.4%	-10.2%
PM_{10}	15.9%	-~~-13.4~~13.7%	23.2%	-11.7~~-11.5~~%
$PM_{2.5}$	15.4%	~~-6.4~~-6.8%	25.6%	~~-5.6~~-5.8%
CO	6.4%	-7.0%	2.3%	-5.5%
O_3	0.9%	~~1.4~~1.3%	1.6%	~~1.1~~0.9%

Met.: the change percentage of species in Exp.2 based on Exp3, represents the effect of meteorology.
Red.: the change percentage of species in Exp.1 based on Exp 2, represents the effect of Nanjing local emission reduction.

The decrease of SO_2 might due to the limit and halt of power plants and improvement of coal-combustion. The cut of particulate matter might due to the stop of construction process and use of low ash content coal. Besides, the prohibition of heavy pollution vehicles could contribute to the drop of NO_2 and CO. Also, limiting the production of industries helped to reduce NO_2 and CO. O_3 response under emission control could be complicated to predict due to its non-linearity chemistry (Fu et al., 2012), and reducing NO_2 pollution may have side-effect by increasing O_3 because of the titration effect. On the whole, the meteorological factors~~meteorology~~ and emission reduction during the YOG had opposite effects, and emission reduction played a decisive role in the air quality promotion.

4 Summary and conclusions

The air quality during the 2nd YOG was superior according to the current NAAQS. Both observation and modeling confirmed that stringent emission reductions was effective to ambient air quality promotion during the Youth Olympic Games, especially to SO_2, NO_2, PM_{10}, $PM_{2.5}$ and CO. The simulated impact percentage of emission reductions were -24.6%, -12.1%, ~~-14.5~~-14.8%, ~~-6.9~~-7.3% and -7.2% for SO_2, NO_2, PM_{10}, $PM_{2.5}$, and CO, respectively.

The meteorological conditions in the holding time were inferior to those of the same period in 2013, with ~~more overcast and rainy days,~~ lower temperature and weaker winds, especially during the YOG. Model simulations show that l~~L~~ess favorable weather conditions caused higher concentrations for all species. Thus, emission reduction control is the decisive factor of the air quality improvement during the YOG.

In general, better air quality during YOG benefit a lot from emission reduction, which has set up a good example in air protection for important social events. However, the enhanced concentrations of air pollutants after YOG (in Sept. 2014) suggest that short-term emission control can only ease air pollution effectively but temporarily. Long-term control policies are necessary to ensure pleasant future air quality.

Acknowledgements

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