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 investigated the comments carefully and made corrections which we hope to 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 can be 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. There were some problems with the statistics of simulated particulate matters in the old manuscript, and we have corrected them 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. Besides, the appendixes are the change list and the marked-up manuscript.

Sincerely,
Qian Huang

Reviewer 1

Comment 1: This manuscript added some contents after the revision. However, its English still needs improvements.

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

Reviewer 2

Comment 1: I don't think the 9 sites around downtown can represent the whole Nanjing, but I understand the possible limitation of available observation for this study.

Response: Thank you for your comment. Nanjing is a highly urbanized city. Up to now, there are only 9 state air monitoring sites in Nanjing in total. The 9 sites include urban sites and suburban sites. Besides, the Nanjing Environmental Protection Bureau takes the 9 sites to represent the whole Nanjing and releases online official air quality data every day. Thus, we have no choice but to choose the state air monitoring sites to represent the whole city.

Comment 2: Although only $PM_{2.5}$ observational data is presented in this study, I still suggest you present model simulated changes in both primary and secondary $PM_{2.5}$ due to emission reduction, which may help explain the weak $PM_{2.5}$ response (just 9.8%), I also think that discussion about $PM_{2.5}$ components will make the manuscript to be more comprehensive.

Response: Thank you very much for your advice. We have added the discussion about model simulated changes in both primary and secondary particulate matters (PM) including PM_{10} and $PM_{2.5}$ in Section 3.2-3.4. And in the revised manuscript, Fig.11, Fig.12, and Table 6 show the effects of emission reduction on primary and secondary PM, and suggest that emission control has much greater impacts on primary PM than on secondary PM during Aug. 2014.

Comment 3: How to explain the increase of SO_2 concentration (5.1%) although SO_2 emission is reduced by 22.1% in August compared with July 2014? what's the meaning of "unpredictable emissions"? based on the difference between the two sensitivity runs, the increasing SO_2 concentration with reduction of SO_2 emission looks strange, please give more discussion here.

Response: Thank you for your comment. The cutting percentage of SO_2 emission was 25.0% for the whole city. However, the emission reduction was inhomogeneous in the city, which could be larger in non-urban areas and smaller in urban areas. This may be one of the reasons for explaining the higher SO_2 concentration at CCM station in Aug. compared to Jul. (5.1%). For the sensitivity runs, the SO_2 emissions reduction really leads to the decrease of SO_2 concentration.

Comment 4: " This paper tries to discuss the overall impact of meteorological conditions ...... partial decrease is not that important". I am not satisfied with the response, although SO_2, NO_2, PM_{10}, $PM_{2.5}$, CO, and O_3 concentrations increased in terms of domain average, there are large areas of concentration decrease for these species, especially for O_3, which require a detailed analysis of these changes in response to variations of meteorological variables and chemical reactions (such as temperature, cloud, PBL etc.)

Response: Thank you for your comment. We have added detailed discussions about the spatial pollutant changes in response to variations of meteorological variables and chemical reactions in revised Section 3.2. For SO_2, NO_2, PM_{10}, $PM_{2.5}$, CO, and O_3, their levels were increased in Aug. 2014 in terms of the city mean. Besides, for SO_2, NO_2, PM_{10}, $PM_{2.5}$, CO, PM_{10p}, PM_{10s}, $PM_{2.5p}$, and $PM_{2.5s}$, there were some small decreasing areas in the northeast Nanjing, which could be caused by the effect of predominant winds. In domain 4, the simulated predominant wind was northeast wind in Aug. 2014, while that was southeast wind in Aug. 2013. So, the simulated diffusion condition of northeast Nanjing might be better in Aug. 2014. For O_3, increasing concentrations were shown in northern and eastern Nanjing, while decreasing concentrations occurred in some southern areas during Aug., 2014, which corresponded well to the distribution of cloud cover. Cloud cover could affect the production of ozone by affecting radiation.

Comment 5: The authors corrected errors in Fig. 8 by reruning the model using corrected emission inventory.

Response: Thank you for your comment.

Comment 6: From the figure 10, a clear impression is emission reduction has little effect on reducing $PM_{2.5}$ (PM_{10}) level in Nanjing, which appear not to support the conclusion in this manuscript " emission reduction is the dominant factor of the air quality improvement during the YOG". Besides, in fig. 10, the changes due to emission reduction is hardly to see for species other than SO_2 and NO_x, is it possible to use different scales for the changes from meteorology and emission reduction?

Response: Thank you for your comment. We use “very important” instead of “dominant” in the revised manuscript. We have revised Fig. 12 (the original Fig. 10) in Section 3.4 and added more species (PM_{10p}, PM_{10s}, $PM_{2.5p}$, and $PM_{2.5s}$) , which show day-to-day simulated effect of meteorology and emission reduction effects during the whole month. As you can see, most of the time, meteorological conditions and emission reduction had opposite effects on pollutants (SO_2, NO_2, PM_{10}, $PM_{2.5}$, CO, PM_{10p}, PM_{10s}, $PM_{2.5p}$, and $PM_{2.5s}$), especially during the YOG (16-28, Aug., 2014). Emission control always played a positive role and cut down the pollutant levels during the whole month, while weather conditions could play a negative role. Table 6 (in Section 3.4) illustrated the opposite effects. These all indicated that emission reduction is the very important factor for air quality improvement during the YOG. Though, the emission reduction percentage was 42.8% for PM_{10}, 36.2% for $PM_{2.5}$ for the whole city, a considerable part of the cutting contribution was from point sources. Compared to area sources, point sources had much less effect on air pollutants at the ground level. Besides, the emission reduction was not even. All of these could result in less effect on reducing pollutants in simulation. For primary particles, emission abatement independently led to a 39.6% decrease in PM_{10p} and a 26.2% decrease in $PM_{2.5p}$. For secondary particles, emissions of SO_2, NO_x and NH_3 contribute to the production of sulfate, nitrate and ammonium salt, respectively. And no control in the emission of NH_3 could weaken the reduction effect on PM_{10s} and $PM_{2.5s}$.

The details about setting of the simulation schemes were in Section 2. The emission reduction simulation schemes were based on the local government emission controls during the 2nd YOG. If we increase the intensity of emission reduction, of course the effect of emission abatement will be more obvious, but it is not reasonable for discovering the influence factor during the 2nd YOG. 2013 is a normal meteorological year, and it is reasonable to be used in the simulation. Thus, we think it unnecessary to use different scales for the changes from meteorology and emission reduction.

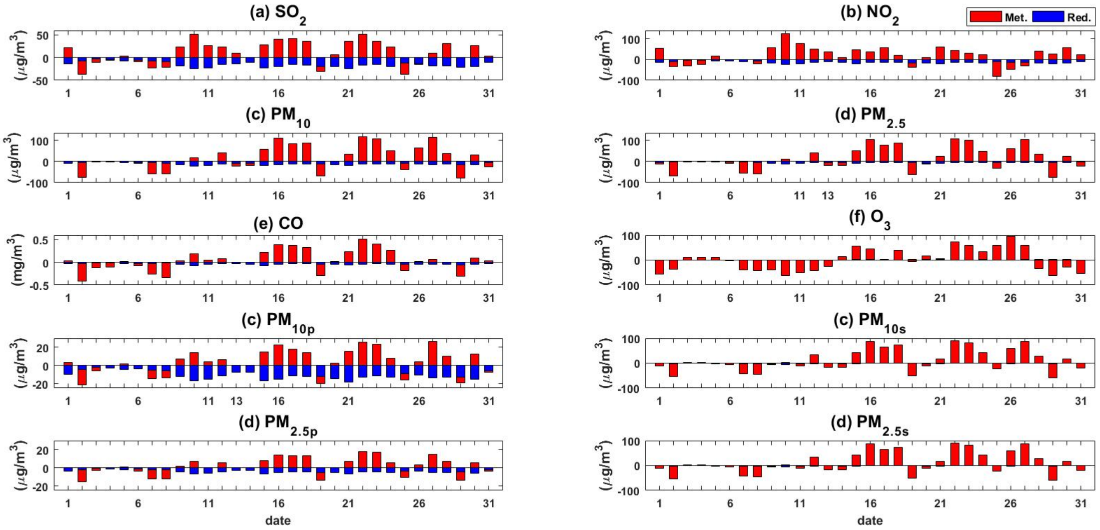


Fig. 12. The simulated effect of meteorology and reduction on pollutant concentrations in Nanjing during 1-31 Aug. , 2014, Met. (Exp.2-Exp.3) represents the effect of meteorology, while Red. (Exp.1-Exp.2) represents the simulated effect of reduction.

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)	Met. (NJ)	Red. (NJ)
SO_2	17.4%	-24.3%	14.1%	-19.2%	17.5%	-24.6%
NO_2	15.1%	-11.7%	12.4%	-10.2%	16.9%	-12.1%
PM_{10}	15.6%	-13.9%	22.4%	-11.9%	18.5%	-15.1%
$PM_{2.5}$	14.9%	-7.5%	24.5%	-6.3%	18.8%	-8.1%
CO	6.4%	-7.0%	2.3%	-5.5%	7.8%	-7.2%
O_3	0.9%	1.3%	1.6%	0.9%	0.7%	1.5%
PM_{10p}	13.2%	-38.3%	5.9%	-33.2%	12.6%	-39.6%
PM_{10s}	16.7%	-2.4%	29.4%	-2.9%	21.5%	-2.9%
$PM_{2.5p}$	8.4%	-25.8%	4.9%	-20.1%	9.5%	-26.2%
$PM_{2.5s}$	16.7%	-2.4%	29.4%	-2.9%	21.5%	-2.9%

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.

Comment 7: It's OK to keep the tables if the authors think they are necessary.

Response: Thank you for your comment.

Comment 8: The authors clarify the questions.

Response: Thank you for your comment.

Reviewer 3

Comment 1: The authors have made substantial improvement of this version of the manuscript, and most of the reviewer's comments were addressed. The quality of the figures and the language need technical corrections. For example, the marks in Fig.1 is not clear.

Response: Thank you for your comment. We have checked and revised some figures including Fig. 1. Besides, the co-authors have helped to modify and improve the English in the manuscript carefully.

Change list:

1. **Line 5-14:** Adjust the affiliation of the first author.

2. **Line 29, 32, 34, 36:** Revise the Abstract.

3. **Line 58, 60, 61, 64, 89, 99, 100, 102, 106, 107:** Revise Section 1 Introduction.

4. **Line 113, 115, 126-127, 134, 153, 155-158:** Revise Section 2 Methodology.

5. **Line 150-163:** Revise Fig. 1, and make it more clear.

6. **Line 165-166:** Revise the caption of Table 1.

7. **Line 174-176, 183:** Rephrase Section 2.3 Emissions and simulation scenarios.

8. **Line 192:** Adjust the arrangement of pictures in Fig. 2.

9. **196, 200-205:** Rephrase Section 2.3 Emissions and simulation scenarios.

10. **Line 208, 223:** Rephrase Section 3.1 Observed air quality during the YOG.

11. **Line 228-229, 233-234:** Revise the caption of Fig. 3 and Fig. 4.

12. **Line 248, 255, 266-267:** Rephrase Section 3.1.

13. **Line 289-290:** Revise the caption of Table 5.

14. **Line 296, 300-339:** Revise Section 3.2 Simulated impact of meteorological conditions.

15. **Line 341-342:** Revise Fig. 7 and the caption of it.

16. Line 347-351: Add a figure (Fig. 8) to show the influence of meteorology on hourly mean concentrations of primary and secondary particulate matters in Aug. 2014 compared with Aug. 2013.

17. Line 353-359: Add more meteorological factors (relative humidity at 2m , cloud fraction, and net downward short wave flux at ground surface) in Fig. 9.

18. Line 370, 373-378: Revise Section 3.3 Simulated impact of emission reduction.

19. Line 379-380: Revise Fig. 10 and the caption of it.

20. Line 385-390: Add a figure (Fig. 11) to show the influence of emission reduction on hourly mean concentrations of primary and secondary particulate matters in Aug. 2014.

21. Line 393-400: Rephrase Section 3.4 Comparison of simulated meteorological factors and emission reduction.

22. Line 402-405: Change Fig. 12 and add more species (PM_{10}p, PM_{10s}, $PM_{2.5p}$, and $PM_{2.5s}$) in it.

23. Line 407-431: Rephrase Section 3.4.

24. Line 433-438: Chang Table 6 and add more species (PM_{10p}, PM_{10s}, $PM_{2.5p}$, and $PM_{2.5s}$) in it.

25. Line 443-452: Rephrase Section 3.4.

26. Line 457-464, 467-473, 475-477: Rephrase Section 4 Summary and conclusions.

27. Add some references as listed below:

Katragkou E., Zanis P., Kioutsioukis I., Tegoulias I., Melas D., Krüger, B. C., and Coppola E.: Future climate change impacts on summer surface ozone from regional climate-air quality simulations over Europe, Journal of Geophysical Research Atmospheres, 116, D22307, doi:10.1029/2011JD015899, 2011.

Pu X., Wang T. J., Huang X., Melas D., Zanis P., Papanastasiou D. K., and Poupkou A.: Enhanced surface ozone during the heat wave of 2013 in Yangtze River Delta region, China. Science of the Total Environment, 603-604, 807-816, doi:10.1016/j.scitotenv.2017.03.056, 2017.

28. Revise the figure and table format to be uniform.

29. Correct the grammar and spelling mistakes throughout the manuscript.

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

Qian Huang [1,2], Tijian Wang [1,*], Pulong Chen [1], Xiaoxian Huang [~~2~~3], Jialei Zhu [4~~3~~], and Bingliang Zhuang [1]

[1] School of Atmospheric Sciences, CMA-NJU Joint Laboratory for Climate Prediction Studies, Jiangsu Collaborative Innovation Center for Climate Change, Nanjing University, Nanjing, 210023, China

[2] Scientific Research Academy of Guangxi Environmental Protection, Nanning, 530022, China

[~~2~~3] College of Plant Science & Technology, Huazhong Agricultural University, Wuhan, 430070, China

[4~~3~~] Department of Climate and Space Sciences and Engineering, University of Michigan, Ann Arbor, 48109, USA

Correspondence to: Tijian Wang (tjwang@nju.edu.cn)

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. 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., 2014), the observed hourly mean ~~observational~~ concentrations of SO_2, NO_2, PM_{10}, $PM_{2.5}$, CO and O_3 were~~as~~ 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 (Level 2). 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 SO_2, NO_2, PM_{10}, $PM_{2.5}$ and CO by 17.5%, 16.9%, ~~19.0~~18.5%, ~~19.5~~18.8%, 7.8% and 0.8%, respectively. Taking account of local emission abatement only, the simulated SO_2, NO_2, PM_{10}, $PM_{2.5}$ and CO was decreased by 24.6%, 12.1%, ~~14.8~~15.1%, ~~7.3~~8.1% and 7.2%, respectively. Consequently, stringent emission control measures can reduce the concentrations of air pollutants in short term, and emission reduction is the very important~~dominant~~ factor ~~of~~for 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., 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 (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. Besides, the local government performed the stringent environmental quality assurance work plan from 1 Aug. (National Bureau of Statistics of China, 2014). The controlled emissions 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. Coal-combustion enterprises were required to use high-quality coals with low sulfur content and ash content. And vehicles with heavy pollution~~ vehicles~~ called "yellow label buses" were prohibited in Nanjing during 10-28 Aug.. Oil loading and unloading operations were strictly controlled. All c~~C~~onstruction processes in the city ~~was~~were forced to stop. Surface with bare soil was covered.

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~~can influence the ~~air quality~~ improvement of local air quality. Emission control has been taken in many social events, like Beijing Olympic Games in 2008 and Shanghai Expo in 2010. Xing et al. (2011) suggested that emission controls benefit for pollutants reduction, 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). 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 cutting down anthropogenic emissions could ~~in~~decrease $PM_{2.5}$

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), 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 the 2nd 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~~during the YOG with those a year ago and the months without emission reduction (Jul. 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~~important factor of the air quality promotion ~~during YOG~~during the YOG, and provides some advice for ensuring pleasant future air quality.

2 Methodology

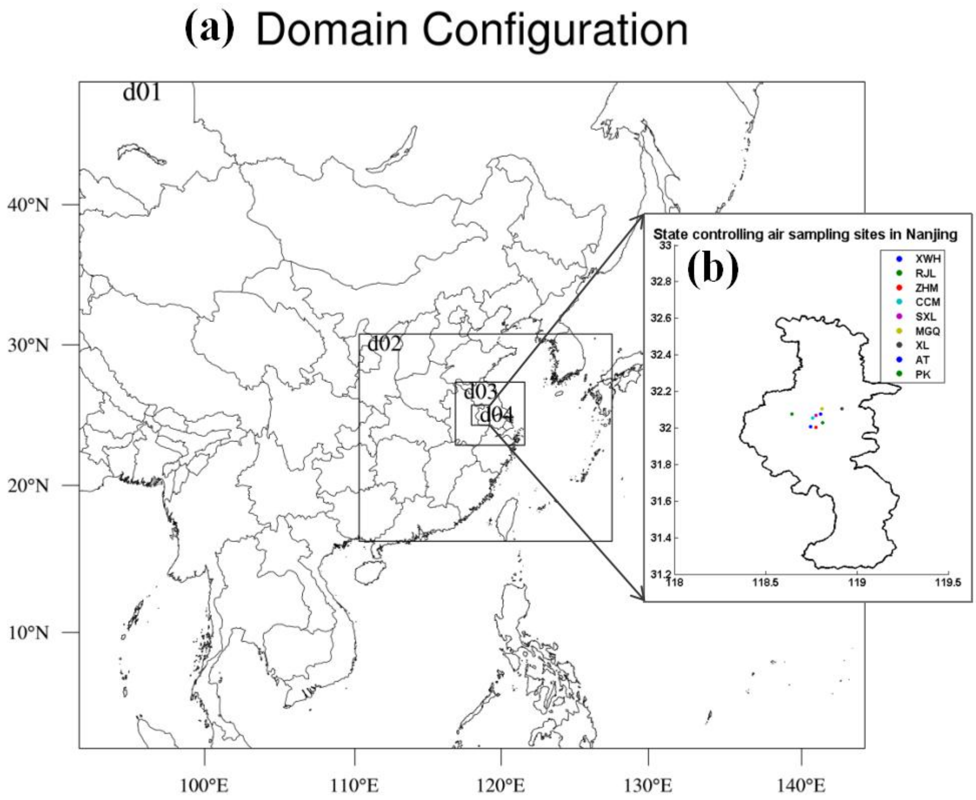
2.1 Data description

Hourly observed air quality data during Jul.- Sept. 2014 and Aug. 2013 of two representative stations was collected from Nanjing Environmental Monitoring Center (http://222.190.111.117:8023/). Both of the two stations are state controlling air monitoring~~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 site calls Xianlin (XL) Station (118.92° E, 32.11° N), which locates in Qixia District, the suburb of Nanjing. Compared to Gulou District, Qixia District is much more sparsely populated with few~~. And there is no~~ traffic congestion problem~~ in Qixia District~~. Thus, XL station was chosen to represent the suburban status of 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). And it was applied to simulate the pollutant distribution over Nanjing in this paper. 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). It 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). 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~~Fig. 1). 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 Shu et al. (2016)'s work~~the research of Shu et al. (2016)~~ and were proven to have good ~~simulation~~ performance. As for the innermost domain, Nanjing ~~Municipal~~ Environmental Protection Bureau chooses the local 9 state controlling air monitoring~~sampling~~ sites (See ~~Fig.1~~Fig. 1, ~~Table1~~Table 1) to represent the whole Nanjing (NJ) city. In conformity with this, the 9 ~~state controlling air sampling~~ sites in domain4 were chosen to represent the whole Nanjing while analyzing the impacts of weather conditions and emission reduction~~model simulation impacts~~.



~~Fig.1~~Fig. 1. Modeling domains and state controlling air monitoring~~sampling~~ sites in Nanjing. ((a) The four nested modeling domains at 81km (d~~D~~01: East Asia), 27km (~~D~~d02: East China), 9km (~~D~~d03: Yangtze River Delta), and 3km (~~D~~d04: Nanjing), (b) Locations of 9 ~~state controlling air sampling~~ sites in Nanjing).

Table 1

The air monitoring~~sampling~~ sites in Nanjing

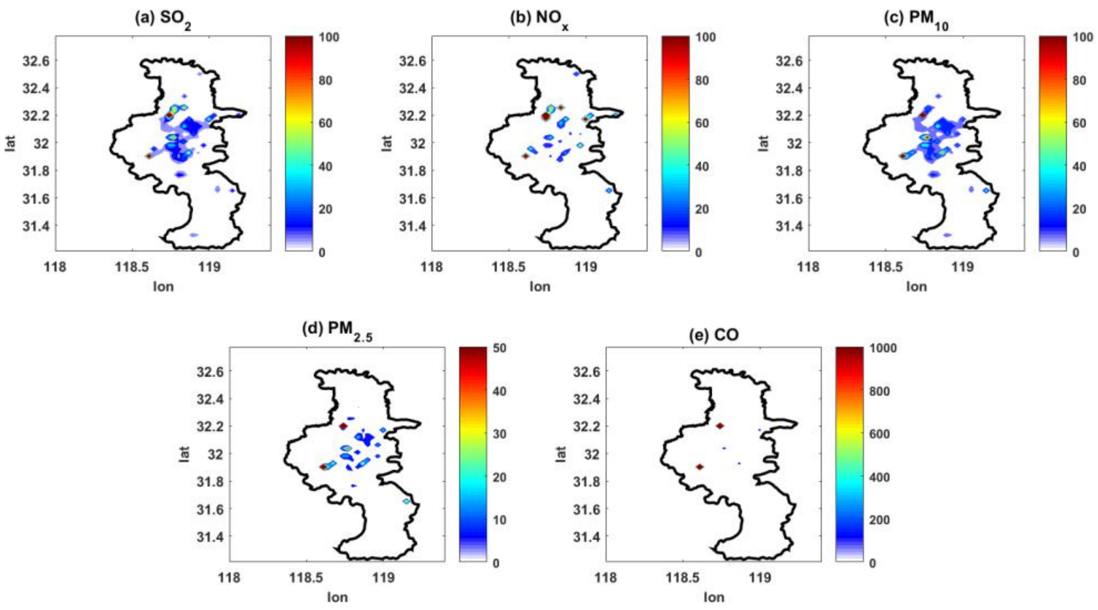
~~Air sampling s~~Sites	Abbreviations	Location
Xuanwuhu Station	XWH	32.08° N, 118.80° E
Ruijinlu Station	RJL	32.03° N, 118.82° E
Zhonghuamen Station	ZHM	32.00° N, 118.76° E
Caochangmen Station	CCM	32.06° N, 118.75° E
Shanxilu Station	SXL	32.07° N, 118.77° E
Maigaoqiao Station	MGQ	32.11° N, 118.81° E
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.~~

For t~~T~~he innermost domain, the local emission inventory before and after emission control was used with a horizontal resolution of 3km × 3km. The base year of the local emission is 2012.~~was based on the local emissions in 2012 (basic emission inventory), and the emissions outside Nanjing city were from MEIC. Besides, 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 emission~~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. 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~~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**~~**Fig. 2**. Emission reduction in domain4 ((a) SO_2, (b) NO_X, (c) PM_{10}, (d) $PM_{2.5}$, (e) CO (unit: t/month)).

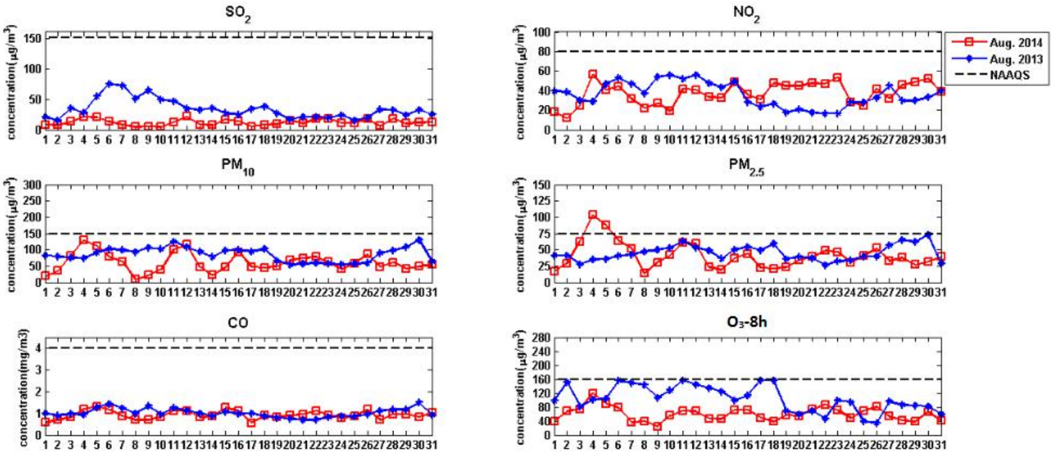
The simulated period was from Jul. 27 to Sept. 1 (China standard time, CST), but only the holding month (1 Aug. to 31 Aug.) was focused on for discussions. In order to better understand the influence of meteorological factors and emission abatement, three experiments were carried out. ~~Exp.1~~Exp. 1 used the weather conditions during Aug. 2014 (CST) and the emission inventory after reduction~~ while~~. ~~Exp.2~~Exp. 2 used the same weather conditions as Exp. 1 with the emission inventory before reduction.

~~Exp.3~~Exp. 3 ~~had~~used the same inventory as ~~Exp.2~~Exp. 2 ~~but ~~and~~used~~ the weather conditions during Aug. 2013 (CST). Besides, ~~Exp.2~~Exp. 2 acted as the control experiment. ~~What's more~~Therefore, ~~Exp.1~~Exp. 1 and ~~Exp.2~~Exp. 2 were ~~set~~performed to ~~study~~investigate the influence of emission reduction on pollutants.~~ only.~~ Similarly, ~~Exp.2~~Exp. 2 and ~~Exp.3~~Exp. 3 were conducted to understand the impact of meteorology on air quality~~ only~~.

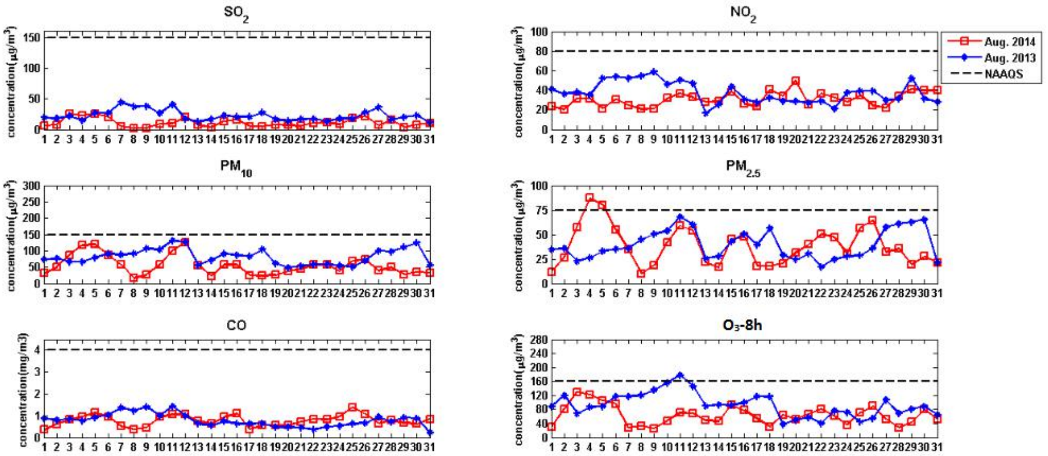
3 Results and discussion

3.1 Observed air quality ~~during YOG~~during the YOG

In the most strictly~~ emission~~ control month Aug. 2014, emission sources including 5 major categories were reduced, and the air quality had great promotion compared to Aug. 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~~Fig. 3, ~~Fig.4~~Fig. 4). The hourly mean pollutant concentration of the two sites during Aug. 2014 is 11.6 $\mu g/m^3$ for SO_2, 34.0 $\mu g/m^3$ for NO_2, 57.8 $\mu g/m^3$ for PM_{10}, 39.4 $\mu g/m^3$ for $PM_{2.5}$, 0.9 mg/m^3 for CO, and 38.8 $\mu g/m^3$ 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. 2014. However, the drop of pollutant concentration could be caused mainly by meteorology conditions or emission reductions. And we will discuss ~~the reason~~this issue based on model simulations in Section 3.2 and Section 3.3.



~~Fig.3~~**Fig. 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. 2013 and Aug. 2014 (CST). Observed data in Aug. 2013 and Aug. 2014 are indicated in blue and red, respectively.~~Observed data in Aug. 2013 are indicated in blue. Observed data in Aug.2014 are indicated in red.~~ NAAQS are indicated in black dotted line.



~~Fig.4~~**Fig. 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. 2013 and Aug. 2014 (CST). Observed data in Aug. 2013 and Aug. 2014 are indicated in blue and red, respectively.~~Observed data in Aug. 2013 are indicated in blue. Observed data in Aug. 2014 are indicated in red.~~ NAAQS are indicated in black dotted line.

Table 2

Statistical analysis of hourly data in Aug. 2013 and Aug. 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. 2014 based on Aug. 2013.

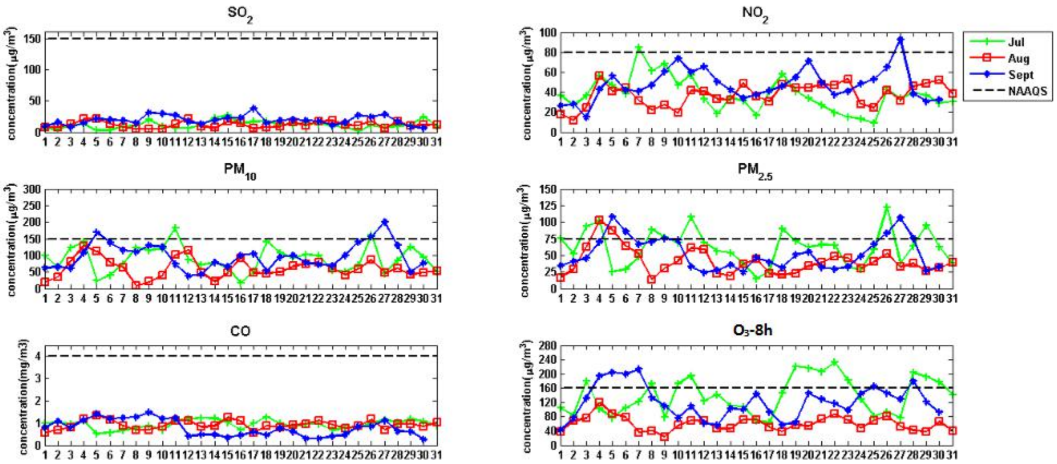
Table 3

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

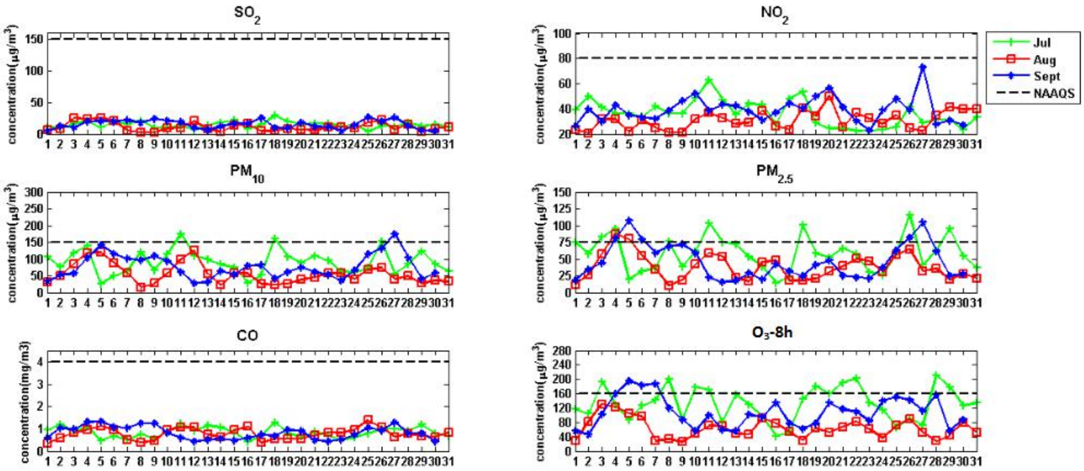
species	time	max	min	mean	median	std	Δ
SO_2	Aug. 2013	139.0	0.0	22.8	19.0	16.1	
	Aug. 2014	71.0	1.0	11.4	8.0	10.4	-50.0%
NO_2	Aug. 2013	129.0	0.0	37.7	32.0	21.7	
	Aug. 2014	95.0	7.0	30.7	27.0	15.0	-18.6%
PM_{10}	Aug. 2013	215.0	0.0	82.1	79.0	32.4	
	Aug. 2014	196.0	6.0	55.2	47.0	35.9	-32.8%
$PM_{2.5}$	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. 2014 based on Aug. 2013.

Analogously, compared the observational data in Aug. 2014 with that in Jul. and Sept. 2014 (the months before and after the most aggressive abatement), the concentrations of most species also decreased obviously. As presented in ~~Fig.5~~Fig. 5 and ~~Fig.6~~Fig. 6, without abatement, NO_2, PM_{10}, $PM_{2.5}$ and O_3 were likely to exceed NAAQS, especially for $PM_{2.5}$ and O_3. As shown in Table 4 and ~~Table5~~Table 5, 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~~to 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). Besides, for most species, the standard deviation was the lowest in Aug., which meant that the potential of extreme events was the least in Aug.. Assume that the weather conditions in Jul., Aug., Sept., 2014 were similar, it can be estimated that emission sources could be the major impact factor of 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, the concentration became higher without emission control~~ they could 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.5~~**Fig. 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., Aug. and Sept. 2014 (CST). Observed data in Jul., Aug. and Sept. 2014 are indicated in green, red and blue, respectively. NAAQS are indicated in black dotted line.



~~Fig.6~~Fig. 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., Aug. and Sept. 2014 (CST). Observed data in Jul., Aug. and Sept. 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. - Sept. 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.2014 based on Jul. 2014.
Δb: the change percentage of species in Aug. 2014 based on Sept. 2014.

Table 5

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

species	month	max	min	mean	median	std	Δa	Δb
SO_2	Jul. 2014	61.0	1.0	14.5	12.0	10.3		
	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		
NO_2	Jul. 2014	123.0	9.0	36.4	33.0	18.9		
	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		
PM_{10}	Jul. 2014	300.0	4.0	91.3	85.0	48.9		
	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		
$PM_{2.5}$	Jul. 2014	158.0	2.0	58.2	51.0	34.8		
	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		
CO	Jul. 2014	2.0	0.3	0.8	0.8	0.4		
	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		
O_3	Jul. 2014	238.0	2.0	78.4	67.0	55.6		
	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		

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

3.2 Simulated impact of meteorological conditions

In this paper, the model configurations were the same as those set by Shu et al.

(2016), who has evaluated the model performance of WRF/CMAQ and proved the model's reliability in simulating air quality in Nanjing.

As we know, m~~M~~eteorology 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~~Exp. 2 and ~~Exp.3~~Exp. 3) use the same emission inventory but different weather conditions, it can be concluded that the higher concentrations may result from poor meteorological~~y~~ conditions. According to model simulation, ~~Exp.2~~Exp. 2 exhibited higher pollutant concentrations for all species in most part of Nanjing as shown in ~~Fig.7~~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~~18.5%, ~~19.5~~18.8%, 7.8% and 0.8% during Aug. 2014 compared to Aug. 2013. Besides, the contributions of meteorological conditions to primary and secondary particulate matters differed (See Fig. 8). Secondary PM_{10} (PM_{10s}) was raised by 21.5%, while primary PM_{10} (PM_{10p}) rose by 12.6% during Aug. 2014 compared to Aug. 2013. And secondary $PM_{2.5}$ ($PM_{2.5s}$) was increased by 21.5%, while primary $PM_{2.5}$ ($PM_{2.5p}$) was added by 9.5%. Thus, the weather conditions had a slightly greater impact on secondary fine particulate matters. Moreover, for SO_2, NO_2, PM_{10}, $PM_{2.5}$, CO, PM_{10p}, PM_{10s}, $PM_{2.5p}$, and $PM_{2.5s}$, there were some small decreasing areas in the northeast Nanjing (Fig. 7 and Fig. 8). In domain 4, the simulated predominant wind was northeast wind in Aug. 2014, while that was southeast wind in Aug. 2013. So, the diffusion condition of northeast Nanjing might be better in Aug. 2014 and resulted in small decrease in these areas.

The overall increasing pollutant levels in Aug. 2014 sugge~~u~~sted that~~at is to say,~~ the diffusion conditions in Aug. 2014 were worse than those in Aug. 2013. Focus on the weather conditions during the YOG holding period (16-28 Aug., 2014) and the same period in 2013, t~~T~~he simulated hourly mean 10-m wind speed in Nanjing was larger~~ in Aug. 2013, especially~~ in 16-28 Aug., 2013, and it was 1.5 m/s larger than that of 16-28 Aug., 2014 (~~Fig.~~Fig. 9~~8~~). Also, the simulated 2-m temperature was higher~~ in Aug. 2013, especially~~ in 16-28 Aug., 2013, and it was 2.0 K larger than that of 16-28 Aug., 2014 (~~Fig.~~Fig. 9~~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.~~Fig. 9~~8~~). Larger wind speed and higher PBLH benefited the diffusion of air pollutants. Warming on the ground surface was conductive to the promotion of convective instability and was also good for the vertical dilution and diffusion of pollutant. Thus, the ~~simulation meteorological~~diffusion conditions in 16-28 Aug. 2013 were better than those in 16-28 Aug. 2014. Rather worse meteorological conditions in 16-28 Aug. 2014 implied that abatement controls might play a ~~decisive~~more important role in improving air quality in YOG compared with the same period in 2013. What's more, relative humidity, cloud cover and shortwave solar radiation all affect ozone chemical reaction (Katragkou et al., 2011; Pu et al., 2017). The generation and photochemical reaction of surface ozone depends on the availability of solar radiation. During the heat wave period, less relative humidity leads to less cloud cover, which could result in more net downward shortwave solar radiation and more production of O_3 (Pu et al., 2017). For ordinary O_3, its production also corresponded well to the cloud cover. As shown in Fig. 9, more relative humidity resulted in more cloud cover in northern and eastern Nanjing during 16-28 Aug., 2013, which resulted in less O_3 in Aug. 2013, but more O_3 in Aug. 2014 (Fig. 7).

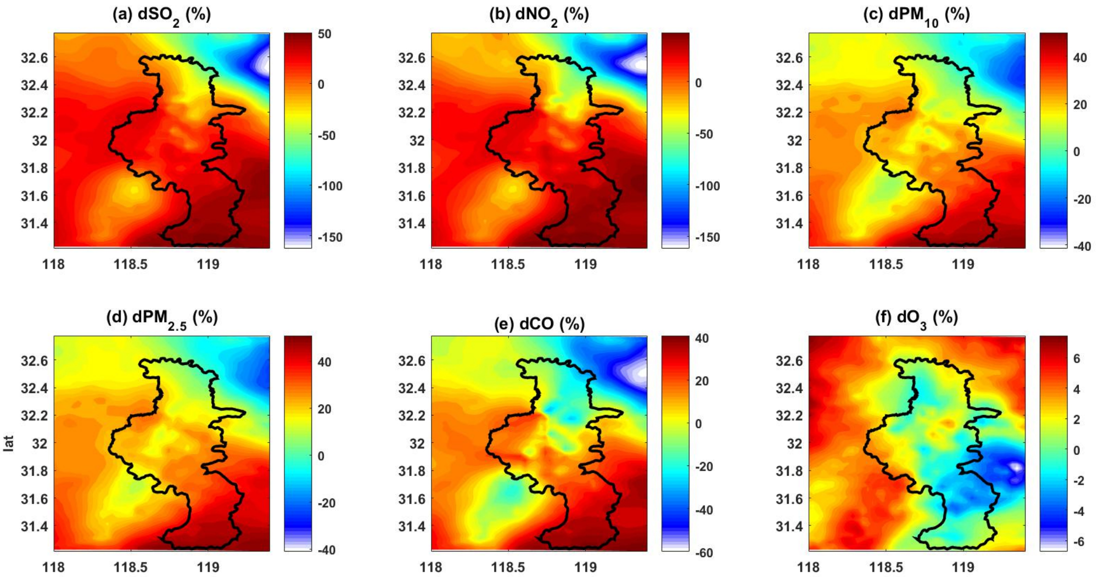


Fig. 7. Influence of meteorology on hourly mean concentrations of air pollutants in Aug. 2014

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. 2 - ~~Exp.3~~Exp. 3)/~~Exp.2~~Exp. 2 * 100%) of SO_2, NO_2, PM_{10}, $PM_{2.5}$, CO, and O_3, respectively.).

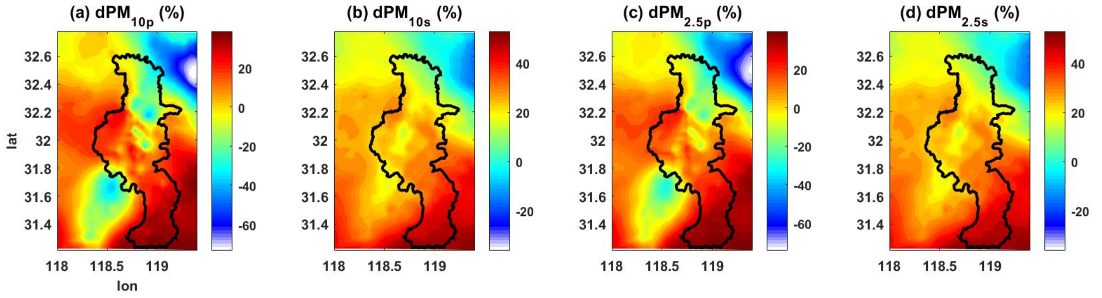


Fig. 8. Influence of meteorology on hourly mean concentrations of primary and secondary particulate matters in Aug. 2014 compared with Aug. 2013. (Black thick lines draw the outline of Nanjing. Picture a - d are hourly average values of impact percentage (dspecies (%)= (Exp. 2 - Exp. 3)/Exp. 2 * 100%) of PM_{10p}, PM_{10s}, $PM_{2.5p}$, and $PM_{2.5s}$, respectively.)

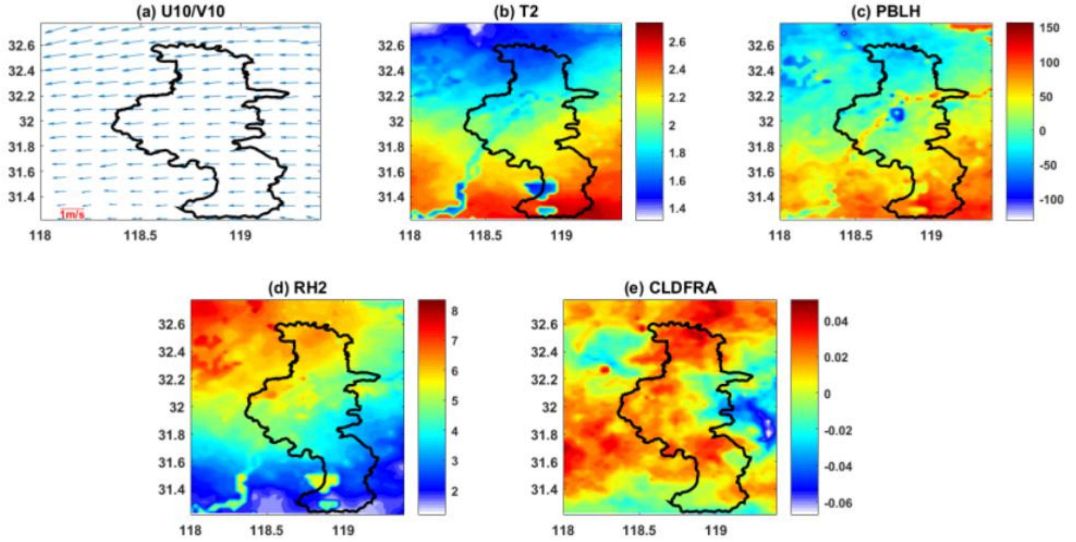
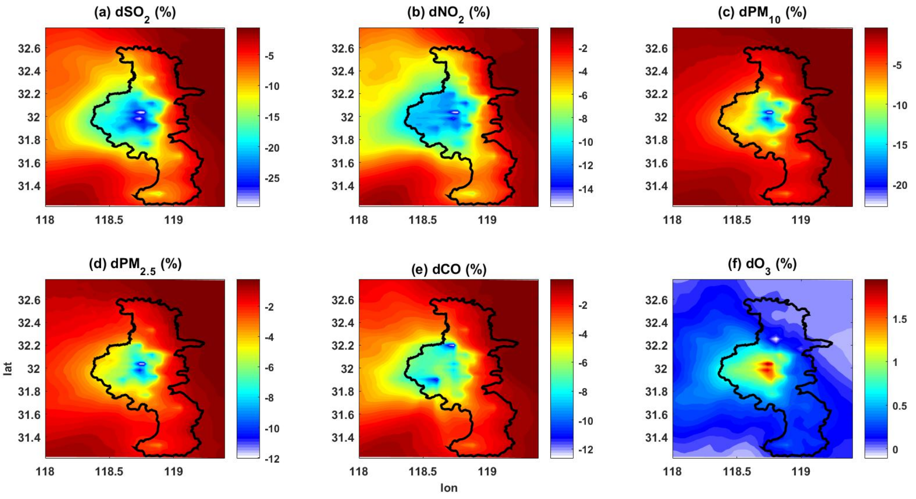


Fig. 9~~8~~. Bias of simulated hourly mean meteorological conditions during the YOG. (Bias = Meteorological Factors in 16-28 Aug., 2013 - Meteorological Factors in 16-28 Aug., 2014. (a) Bias of Wind at 10m during 16-28 Aug. (unit: m/s), (b) Bias of temperature at 2m during 16-28 Aug. (unit: K), (c) Bias of planetary boundary layer height during 16-28 Aug. (unit: m), (d) Bias of relative humidity at 2m during 16-28 Aug. (unit: %), (e) Bias of cloud fraction during 16-28 Aug.).

3.3 Simulated impact of emission reduction

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. 10~~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~~Fig. 2). Besides, impact percentages (dspecies (%) = (~~Exp.1~~Exp. 1 - ~~Exp.2~~Exp. 2)/ ~~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 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~~15.1%, ~~7.3~~8.1% and 7.2% during Aug. 2014. As for O_3, the variation was positive (1.3%), especially in the downwind area of NO_x with heavy reduction~~ region~~, which might due to the less titration of O_3 by NO_x (Liu et al., 2013; Dong et al., 2013). For primary and secondary particulate matters, the influence of emission reduction varied dramatically. As shown in Fig. 11, PM_{10p} was dropped by 39.6%, while PM_{10s} only declined by 2.9%. And $PM_{2.5p}$ was decreased by 26.2%, while $PM_{2.5s}$ merely cut down by 2.9%. It seems that emission controls had much more impacts on primary pollutants, especially on coarse particulate matters.



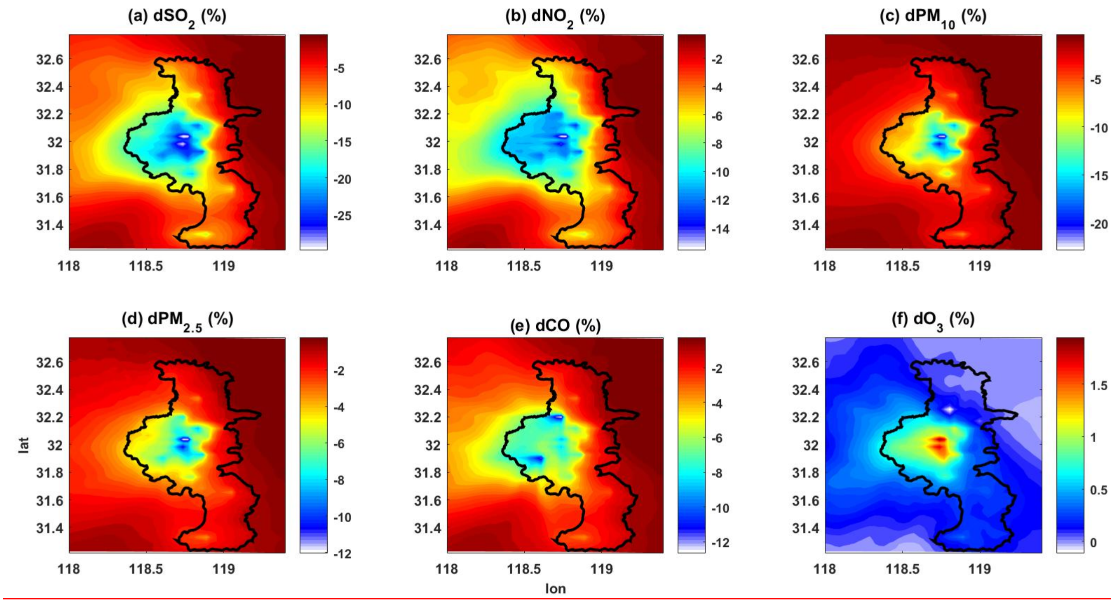


Fig. 10~~9~~. Influence of emission reduction on hourly mean concentrations of air pollutants in Aug. 2014. (Black thick lines draw the outline of Nanjing. Picture a - f are hourly average values of impact percentage (dspecies (%) = (~~Exp.1~~Exp. 1 - ~~Exp.2~~Exp. 2)/ ~~Exp.2~~Exp. 2*100%) of SO$_2$, NO$_2$, PM$_{10}$, PM$_{2.5}$, CO and O$_3$, respectively.).

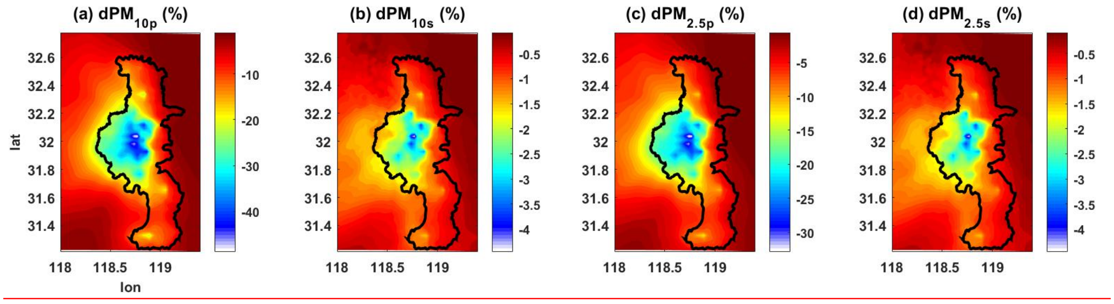


Fig. 11. Influence of emission reduction on hourly mean concentrations of primary and secondary particulate matters in Aug. 2014. (Black thick lines draw the outline of Nanjing. Picture a - d are hourly average values of impact percentage (dspecies (%) = (Exp. 1 - Exp. 2)/ Exp. 2*100%) of PM$_{10p}$, PM$_{10s}$, PM$_{2.5p}$ and PM$_{2.5s}$, respectively.).

3.4 Comparison of simulated meteorological factors and emission reduction

~~Fig.1~~Fig. 12~~0~~ displays the simulated effect of meteorological factors and emission reduction in Nanjing on air quality improvement during~~ YOG (16-28~~ Aug.~~,~~ 2014~~)~~. In general, meteorological conditions played a negative role in air quality promotion in most days, only played a positive role in a few days. And the negative effect of weather conditions exceeded its positive effect during the whole month (See discussion in Section 3.2). On the other hand, emission reduction contributed to the decline of SO_2, NO_2, PM_{10}, $PM_{2.5}$, CO, PM_{10p}, PM_{10s}, $PM_{2.5p}$, and $PM_{2.5s}$ all the time, especially for primary coarse particulate matters. However, reduction of NO_x could cause~~d~~ a slight rise of O_3.~~ This signifies that emission abatement was the crucial factor of the air quality promotion during YOG.~~

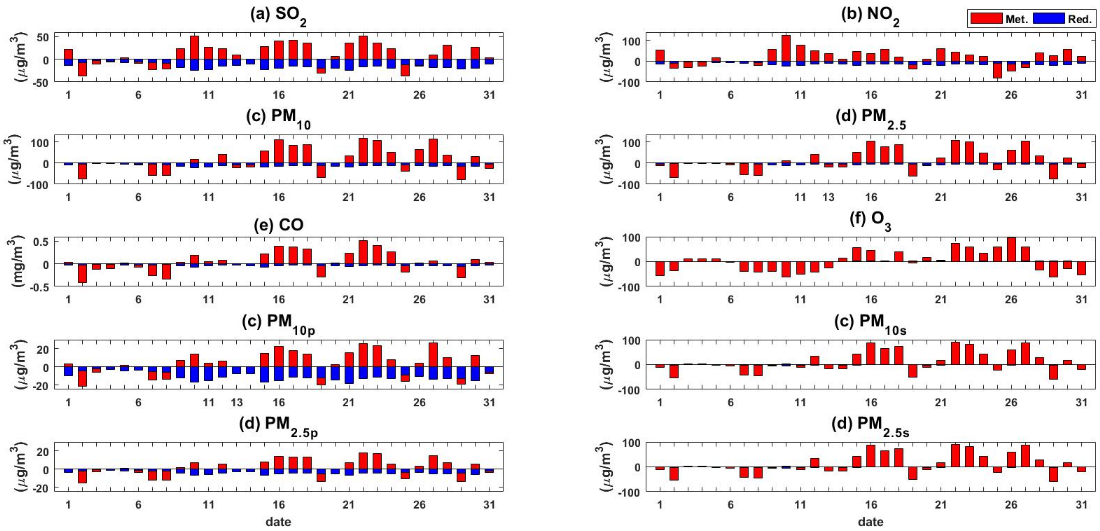


Fig. 12~~0~~. The simulated effect of meteorology and reduction on pollutant concentrations in Nanjing during ~~the YOG (~~1~~16~~-31~~28~~ Aug. , 2014~~)~~, Met. (~~Exp.2~~Exp. 2-~~Exp.3~~Exp. 3) represents the effect of meteorology, while Red. (~~Exp.1~~Exp. 1-~~Exp.2~~Exp. 2) represents the simulated effect of reduction.

~~Besides~~Moreover, the~~their~~ opposite effects of meteorology and emission abatement on SO_2, NO_2, PM_{10}, $PM_{2.5}$, CO, PM_{10p}, PM_{10s}, $PM_{2.5p}$ and $PM_{2.5s}$ during the whole month were more apparent~~ at specific sites~~ as statistically listed in Table 6. CCM station represents the urban status~~, and~~ XL station represents the suburban status and NJ represents the whole city. Adverse meteorology was found to raise the concentration of the six pollutants as 17.4% for SO_2, 15.1% for NO_2, ~~15.9~~15.6% for PM_{10}, ~~15.4~~14.9% 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~~22.4% for PM_{10}, ~~25.6~~24.5% for $PM_{2.5}$, 2.3% for CO, and 1.6% for O_3 at XL station. On the contrary, emission abatement reduced their levels in most cases, especially in the urban site. It see~~m~~ms that the levels of air pollutants reduced ~~with ~~more~~ extent~~ at CCM station compared to XL 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%, ~~13.7~~13.9%, ~~6.8~~7.5% and 7.0%, respectively at CCM station, ~~whose decrease range was~~being larger by 1.0% to 2.0% compared with XL station. Though O_3 under emission reduction scenarios resulted in a slightly rise (0.9% to 1.3%) at both sites,– the effectiveness of emission abatement was remarkable generally. As for primary and secondary particulate matters, meteorological factors also played a negative role during Aug. 2014, and had slightly more effect on secondary fine particles. Emission controls seemed to cause tremendous impact on primary particulate matters, especially for primary coarse particles. Emission abatement led to a 38.3% decrease in PM_{10p} at CCM station, a 33.2% decrease in PM_{10p} at XL station, and a 39.6% decrease in PM_{10p} for the whole city. For secondary particulate matters, including sulfate, nitrate, and ammonium salt, emission reduction played rather minor role in cutting the pollutants, with merely a 2.4% decrease in PM_{10s} and $PM_{2.5s}$ at CCM station, a 2.9% decrease in PM_{10s} and $PM_{2.5s}$ at XL station.–

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)	Met. (NJ)	Red. (NJ)
SO_2	17.4%	-24.3%	14.1%	-19.2%	17.5%	-24.6%
NO_2	15.1%	-11.7%	12.4%	-10.2%	16.9%	-12.1%
PM_{10}	~~15.9~~15.6%	-13.~~13.9~~7%	~~23.2~~22.4%	-11.9~~11.7~~%	~~19.0~~18.5%	-~~14.5~~15.1%
$PM_{2.5}$	14.9~~15.4~~%	-~~6.8~~7.5%	~~25.6~~24.5%	-~~5.8~~6.3%	~~19.5~~18.8%	-~~6.9~~8.1%
CO	6.4%	-7.0%	2.3%	-5.5%	7.8%	-7.2%
O_3	0.9%	1.3%	1.6%	0.9%	0.7%	1.5%
PM_{10p}	13.2%	-38.3%	5.9%	-33.2%	~~15.2~~12.6%	-39.6%
PM_{10s}	16.7%	-2.4%	29.4%	-2.9%	~~20.2~~21.5%	-~~2.~~2.9%
$PM_{2.5p}$	8.4%	-25.8%	4.9%	-20.1%	~~14.2~~9.5%	-26.2%
$PM_{2.5s}$	16.7%	-2.4%	29.4%	-2.9%	~~20.2~~21.5%	-~~2.~~2.9%

Met.: the change percentage of species in ~~Exp.2~~Exp. 2 based on Exp3, represents the effect of meteorology.

Red.: the change percentage of species in ~~Exp.1~~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. The cut of particulate matters might due to the stop of construction process and use of low ash content coal for industry. For secondary particulate matters, controlling the emission of SO_2 and NO_x could help to reduce the formation of sulfate and nitrate, but no control on the emission of NH_3 could still result in quite a part of ammonium salt. The response of O_3 ~~response under~~to 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 and emission reduction during the YOG had opposite effects on SO_2, NO_2, PM_{10}, $PM_{2.5}$, and CO, and emission reduction played a ~~decisive~~very important role in the air quality ~~promotion~~improvement.

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~~were effective to ambient air quality promotion during the Youth Olympic Games, especially to SO_2, NO_2, PM_{10}, $PM_{2.5}$ and CO. Compared to Aug. 2013, the observed concentrations in Aug. 2014 were 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. The simulated impact percentage of emission reductions were -24.6%, -12.1%, -~~14.8~~15.1%, -~~7.3~~8.1% and -7.2% for SO_2, NO_2, PM_{10}, $PM_{2.5}$, and CO, respectively.

The meteorological conditions in the holding time of the YOG were inferior to those of the same period in 2013, with lower temperature and weaker winds~~, especially during the YOG~~. Model simulations show that less favorable weather conditions caused higher concentrations for all species, including ~~, and the distribution of~~ O_3 which was increased due to ~~corresponded well to~~ less cloud cover.

Besides, meteorological conditions had slightly more effect on secondary fine particular matters compared to primary fine particular matters. Emission reduction could cut down the levels of SO_2, NO_2, CO and particular matters, especially for primary coarse particles. Thus, emission reduction control is ~~the~~the ~~decisive~~very important factor ~~of~~for the air quality improvement during the YOG.

In general, better air quality ~~during YOG~~during the 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 the YOG (in Sept. 2014) suggest that short-term emission control can only ease air pollution effectively and ~~but~~ temporarily. Long-term control policies are necessary to ensure pleasant future air quality.

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