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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 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 (August, 2014), the 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 China National Ambient Air Quality Standard. However, simulation showed that the weather conditions such as weaker winds during the holding time were adverse for better air quality, and 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, SO_2, NO_2, PM_{10}, $PM_{2.5}$ and CO was decreased by 24.6%, 12.1%, 14.5%, 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 August, 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).

In order to realize the promise of “Green YOG”, the local government had taken a series of measures to reduce emissions of air pollutants. Preparatory work were carried out since 1 July, 2014. Besides, 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 sources 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, heavy pollution vehicles called “yellow label buses” were prohibited in Nanjing during 10-28 August, transfer benefits of public transportation were offered, unloading operations were strictly controlled.

It is well known that air quality is 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. Jia et al. (2011) suggested that emission controls benefit for all pollutants reductions, 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. 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. Xu et al. (2013) concluded that $PM_{2.5}$ was mainly emitted from anthropogenic sources other than biogenic sources. Dong et al. (2013) found that independent NO_x emission reduction would strengthen O_3 as a side effect in YRD.

There have been some studies on air quality during the 2nd YOG (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 without emission reduction month (July, 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 July- September 2014 and August 2013 of two representative stations was from Nanjing Environmental Monitoring Center (http://222.190.111.117:8023/). 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 v4.7.1, Binkowski and Roselle, 2003) model includes the 2005 Carbon Bond gas-phase mechanism (CB05) and the AERO4 aerosol module, and 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. 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).

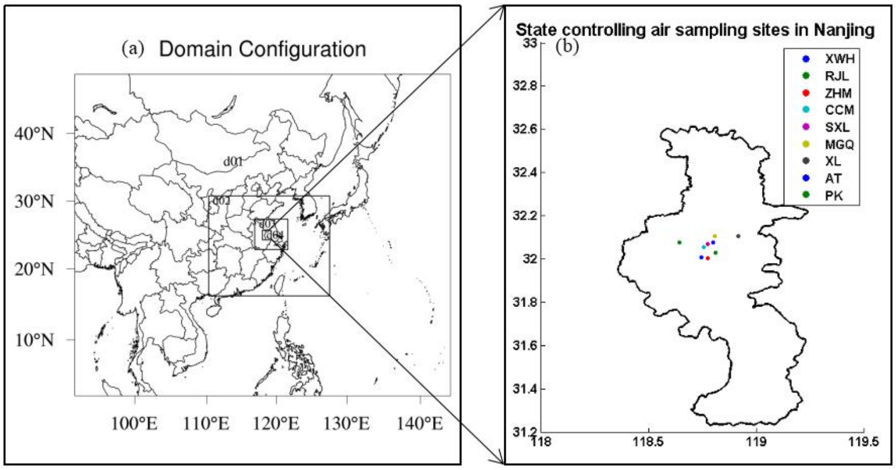

Fig.1. Modeling areas and state controlling air sampling sites in Nanjing. ((a) The four nested modeling domains at 81km (D01: East Asia), 27km (D02: East China), 9km (D03: Yangtze River Delta), and 3km (D04: Nanjing), (b) Locations of 9 state controlling air sampling sites in Nanjing).

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 simulated period was from Jul. 27 to Sept. 1 (CST), but only the holding month (Aug. 1 to Aug. 31) was focused on. In order to better understand the influence of meteorology and emission abatement, three experiments were carried out. Exp.1 used the weather conditions during August 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 the weather conditions during August 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 contaminants only.

3 Results and discussion

3.1 Air quality during YOG

In the most strictly emission control month August 2014, over 30 kinds of pollutant emissions were reduced, 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 August 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) (Fig2, Fig3). 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) revealed that concentrations of air pollutants varied more steadily in August 2014. These results indicated that emission reductions did help the alleviation of air pollution and cut down the possibility of extreme events occurrence.

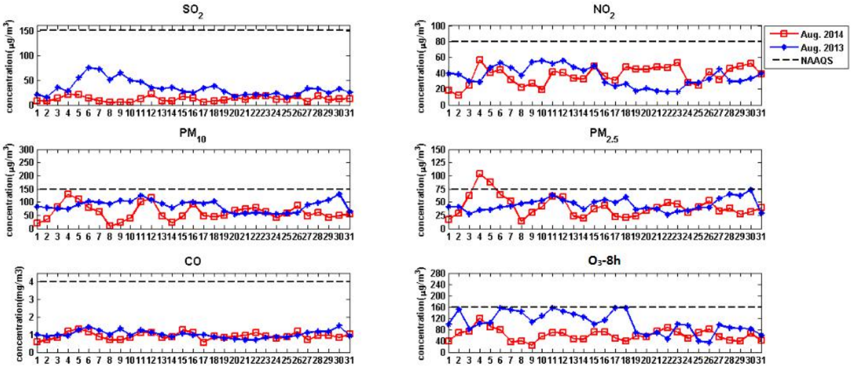

Fig.2. Day-to-day variations in SO_2, NO_2, PM_{10}, $PM_{2.5}$, CO and O_3-8h at CCM station in August 2013 and August 2014 (CST). Observed data in August 2013 are indicated in blue. Observed data in August 2014 are indicated in red. NAAQS are indicated in black dotted line.

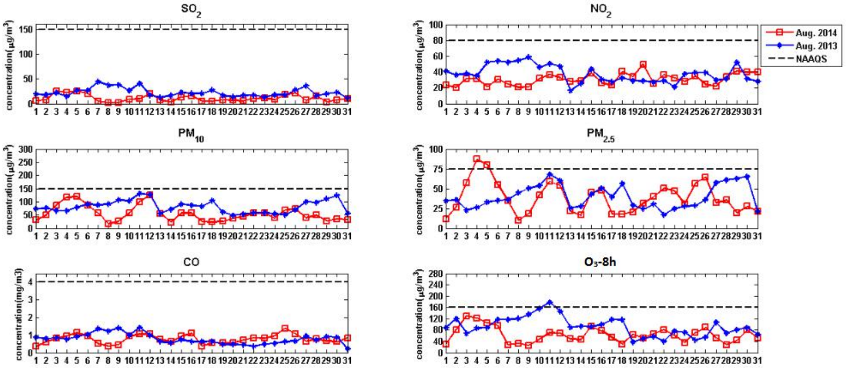

Fig.3. Day-to-day variations in SO_2, NO_2, PM_{10}, $PM_{2.5}$, CO and O_3-8h at XL station in August 2013 and August 2014 (CST). Observed data in August 2013 are indicated in blue. Observed data in August 2014 are indicated in red. NAAQS are indicated in black dotted line.

Table 2

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

Table 3

Statistical analysis of hourly data in August 2013 and August 2014 at XL station (The unit is $\mu g/m^3$ 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 August 2014 based on August 2013.

Analogously, compared the observational data in August 2014 with that in July and September 2014 (the months before and after the most aggressive abatement), most species had a good reflection in August. As presented in Fig.4 and Fig.5, without abatement, NO_2, PM_{10}, $PM_{2.5}$ and O_3 were likely to exceed NAAQS, especially $PM_{2.5}$ and O_3. 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 August, which meant that the potential of extreme events was the least in August. These results proved that concentrations of most species decreased and had less potential in extreme events after aggressive emission abatement. However, they would rebound without emission control.

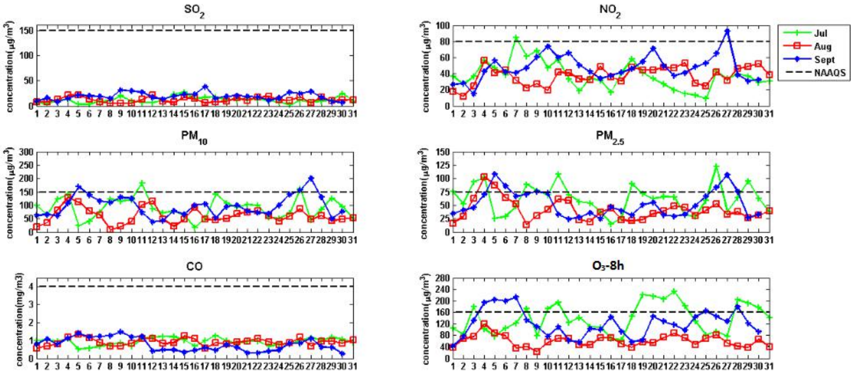

Fig.4. Day-to-day variations in SO_2, NO_2, PM_{10}, $PM_{2.5}$, CO and O_3-8h at CCM station in July, August and September 2014 (CST). Observed data in July, August and September 2014 are indicated in green, red and blue, respectively. NAAQS are indicated in black dotted line.

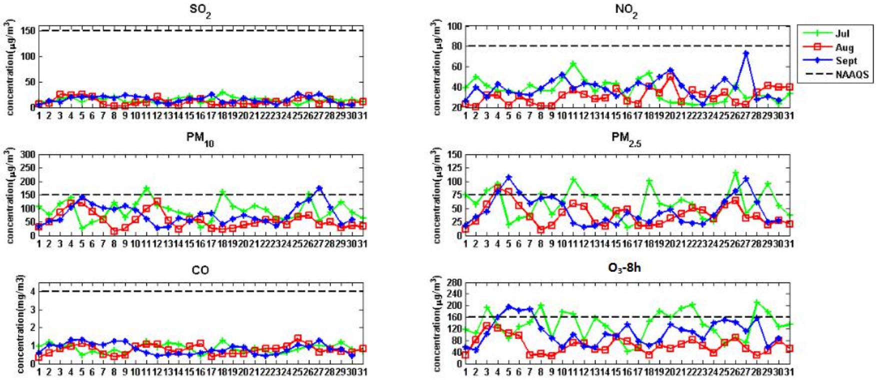

Fig.5. Day-to-day variations in SO_2, NO_2, PM_{10}, $PM_{2.5}$, CO and O_3-8h at XL station in July, August and September 2014 (CST). Observed data in July, August and September 2014 are indicated in green,

red and blue, respectively. NAAQS are indicated in black dotted line.

Table 4

Statistical analysis of hourly data in July - September 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 August 2014 based on July 2014.

Δb: the change percentage of species in August 2014 based on September 2014.

Table 5

Statistical analysis of hourly data in July - September 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		
NO_2	Jul. 2014	123.0	9.0	36.4	33.0	18.9	-15.8%	-21.8%
	Aug. 2014	95.0	7.0	30.7	27.0	15.0		
	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	-39.6%	-28.7%
	Aug. 2014	196.0	6.0	55.2	47.0	35.9		
	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	-34.6%	-17.7%
	Aug. 2014	157.0	3.0	38.0	34.0	24.1		
	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	-7.1%	-4.9%
	Aug. 2014	2.0	0.3	0.8	0.7	0.3		
	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	-50.7%	-39.9%
	Aug. 2014	148.0	2.0	38.7	32.0	28.3		
	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 Impact of meteorological conditions

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). 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 resulted 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. Rather worse meteorological conditions implied that abatement controls might play a decisive role in improving air quality in YOG .

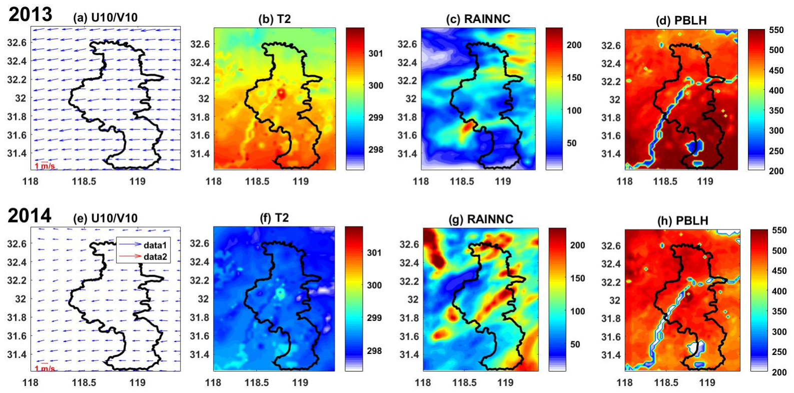

Fig. 6. Simulated meteorological conditions during the YOG. ((a) Wind at 10m in 2013 (unit: m/s), (b) Temperature at 2m in 2013 (unit: K), (c) Accumulated total grid scale precipitation in 2013 (unit: mm), (d) PBL height in 2013 (unit: m), (e) Wind at 10m in 2014 (unit: m/s), (f) Temperature at 2m in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

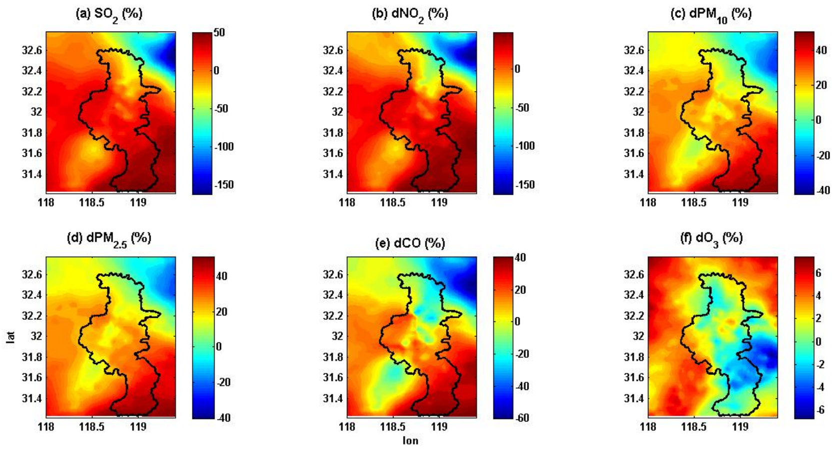

Fig. 7. Influence of meteorology on hourly mean concentrations of pollutants. (Black thick lines draw the outline of Nanjing. Picture a - f are impact percentage (dspecies (%)= (Exp.2 - Exp.3)/Exp.2 * 100%) of SO_2, NO_2, PM_{10}, $PM_{2.5}$, CO, and O_3, respectively.).

3.3 Impact 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, 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. 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 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%, 14.5%, 6.9% and 7.2% during the holding month. As for O_3, a kind of photochemical products, the variation was positive, especially in the heavy reduction region, which might relate to the reduction proportion of NO_x and VOCs (Liu et al., 2013; Dong et al., 2013).

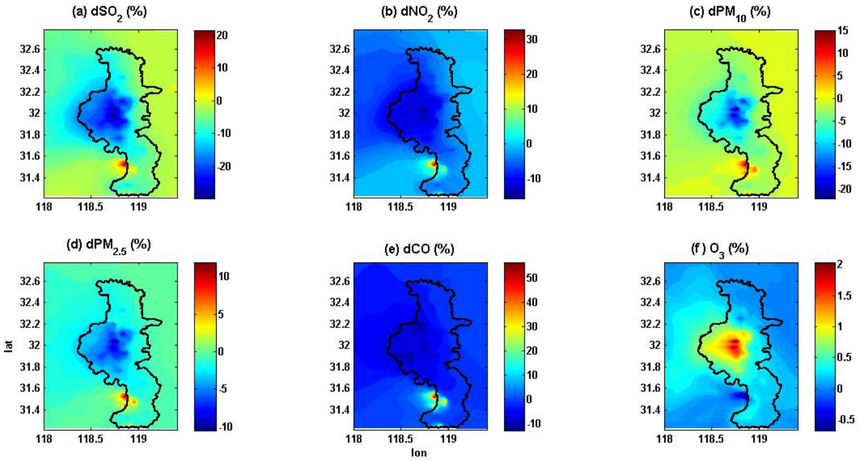

Fig. 8. Influence of emission reduction on hourly mean concentrations of pollutants. (Black thick lines draw the outline of Nanjing. Picture a - f are impact percentage (dspecies (%) = (Exp.1 - Exp.2)/ Exp.2*100%) of SO_2, NO_2, PM_{10}, $PM_{2.5}$, CO and O_3, respectively.).

3.4 Comparison of meteorological factors and emission reduction

Fig.9 displays the effect of meteorological factors and emission reduction on air quality improvement during YOG. 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.

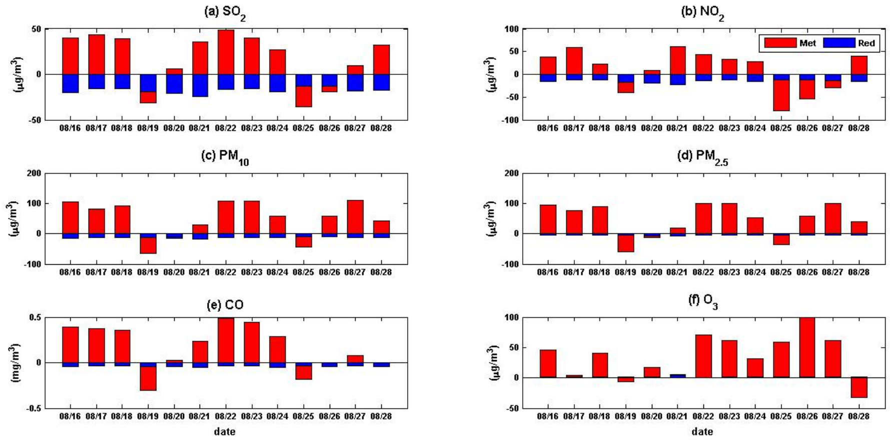

Fig. 9. The simulated effect of meteorology and reduction on pollutant concentrations in Nanjing during the YOG, Met represents the effect of meteorology, while Red represents the effect of reduction.

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 reduction reduced their levels in most cases, especially in the urban site. Pollutants 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%, 6.4% and 7.0%, respectively at CCM station, whose decrease range was larger by 0.9% to 1.5% compared with XL station. Though O_3 under emission reduction scenarios resulted in a slightly rise (1.1% to 1.4%) at both sites, the effectiveness of emission abatement was remarkable.

Table 6

Comparison between the 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%	23.2%	-11.5%
$PM_{2.5}$	15.4%	-6.4%	25.6%	-5.6%
CO	6.4%	-7.0%	2.3%	-5.5%
O_3	0.9%	1.4%	1.6%	1.1%

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 (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 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%, -6.9% 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. Less 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.

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