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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Ozone air quality during the 2008 Beijing Olympics – effectiveness of emission restrictions" *by* Y. Wang et al.

YX Wang

yxw@tsinghua.edu.cn

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We thank Dr. Tao Wang for his very thoughtful and constructive comments.

. . .it is important to consider a shorter-time scale when comparing the role of meteorology and emission reduction, in part because the ozone quality is assessed by an hourly or 8-hourly standard.

We agree with the reviewer that short-term effects of meteorology are important and should be emphasized. We added a table (Table 2) to summarize short-term anomalies (separating the 1st week of August and the Olympics days from the monthly mean) as suggested by the reviewer. We added the following discussions in the text and adjusted our conclusion/abstract accordingly. Although Table 2 shows an increasing role

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of meteorology for air quality on shorter time steps (i.e., weeks), the additional analysis still suggests that emission reduction made significant contributions to air quality improvement during the Olympics.

We believe it is not necessary to push our anomaly analysis to even shorter time steps (i.e., days). On the same calendar day but in different years our site may sample air masses of completely different origins. A comparison in this case does not provide much useful information on pollution changes in Beijing. Averaging anomalies over the whole month would cancel out the daily randomness in meteorology and represent the mean chemical composition of dominating air masses sampled at the site.

(pg 19, line 2 – pg 28): "The meteorology-related anomaly has significant day-to-day variations, ranging from -40 ppb to +40 ppb. In contrast, the emission-driven anomaly is always negative, ranging from -20 ppb to -5 ppb, confirming the benefit of emission restrictions in reducing O3 pollution over Beijing regardless of meteorological conditions. Compared with the meteorology-driven anomaly, the variability in the emission-driven anomaly is much smaller. The good temporal correlation between the meteorology-related and the composite anomaly indicates that the anomaly on individual days is mostly driven by meteorology. Table 2 summarizes mean anomalies for different days in August 2008. The large positive meteorology anomaly during the first week of August (+25 ppb) indicates that high O3 levels during this period were largely meteorology driven, when the atmosphere was stagnant with weak southwesterly winds and high temperature. Although the emission-driven anomaly (-11 ppb) cannot fully compensate for the meteorology-driven anomaly during this period, it reduces the composite anomaly (+14 ppb) to 60% of the meteorology anomaly, suggesting the benefit of reducing emissions of O3 precursors during polluted days. During the Olympics (8 August – 24 August), both the meteorology-driven and emission-driven anomalies are negative, averaging -12 ppb and -10 ppb respectively. The meteorology-driven anomaly appears to account for a slightly larger fraction (55%) of the composite anomaly than the emission-driven anomaly (45%) during this period. However, the

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difference between the two anomalies is only 2 ppb, within typical error bounds of chemical transport models for O3 simulation. Averaged for the whole of August 2008, however, the mean emission-driven anomaly is -8.9 ppb, accounting for 80% of the composite anomaly and larger than the meteorology-driven anomaly (-2.3 ppb) by a factor of 4. We conclude that although the day-to-day variability in ozone is driven mostly by meteorology, the reduction in emissions of ozone precursors associated with the Olympic Games is responsible for at least half of the observed decrease in O3 during August 2008."

Abstract (pg 1, line 26-29): "the reduction in emissions of ozone precursors associated with the Olympic Games had a significant contribution to the observed decrease in O3 during August 2008, accounting for 80% of the O3 reduction for the month as a whole and 45% during the Olympics Period (8-24 August)."

2007 emission for Beijing: it would be good if more detailed information is given on this inventory.

The bottom-up inventory is not conducted by the authors, so we didn't elaborate on the details. The inventory work has been submitted to Environmental Science and Technology (S.X. Wang, et al., Emission reductions and air quality improvements of air quality control measures during the 2008 Olympics in Beijing, Environ. Sci. Tech., submitted, 2009). We updated the reference in the manuscript and added a brief description of the inventory (pg 7, line 24 – pg 8, line 2):

"The inventory for Beijing was developed bottom-up and has a spatial resolution of 4 km x 4 km. It was compiled from detailed energy statistics for Beijing, road network databases, locations of power plants and large industrial facilities, population distribution, and surveys of other key parameters related to activity rates. Emission factors for pollutants were obtained from a detailed technology-based approach reflecting rapid renewal of combustion equipment and processes, combined with field measurements of representative combustion types (S.X. Wang et al., Emission reductions and air qual-

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ity improvements of air quality control measures during the 2008 Olympics in Beijing, Environ. Sci. Tech., submitted, 2009)."

The higher O3 conc. on August 4-6 in 2008 reveals the important role of meteorology or the regional sources despite the large reduction in the emission of ozone precursor in Beijing. The significant decrease in the ozone levels in the later period (Aug 13-23) could be due to changes in winds. Note that the afternoon peaks of 40 ppbv during that period could be indicative of air masses from rural areas. What were wind directions in these periods?

We stated in later section (4.2) that high O3 levels in the first week of August were attributed to meteorology, when the atmosphere was stagnant with weak southwesterly winds and high temperature. We added a clarification to the reader: "which were attributed to unfavorable meteorological conditions to be discussed in Section 4.2"

Figure 3: Why did CO, NOy, and SO2 show max. concentrations in the wind directions of W-NW in 2007? This is very strange as air from that direction should be clean. Was it due to a local (biomass burning) source? I notice that the largest ozone reduction was in air from NE-ENE, and comparable levels of ozone in urban/regional plumes (with the highest NOy). This does not seem to suggest a significant decrease in ozone from Beijing plumes. In using the locally measured winds, caution should be given due to the mountainous topography around the study site.

We explained the wind direction approach in the text (pg, 10, line 17-19):

"Although wind direction measured locally at the site is not equal to the direction from which air masses originate, grouping observations for the whole month by wind direction can still give some statistical association with the origins of air masses."

The maximum mixing ratios of CO, NOy, and SO2 with W-NW winds in 2007 were an interesting feature and we are currently investigating the causes. It's likely due to local sources such as biomass burning. We note that W-NW winds in 2007 were

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quite infrequent, occurring only on a couple of days. As the reviewer suggested, we should use caution when use local wind direction on a single day to represent the origin of air masses. The large O3 reduction in O3 from NNE-NE-ENE was attributed to meteorological conditions with lower temperature and higher RH with those air masses in 2008. We stated explicitly in the text (pg 11, line 3-6):

"winds from the NNE-NE-ENE sector are infrequent at the site in August, and lower O3 mixing ratio for this sector relates to short-term, day-to-day, variability in meteorology and thus can only account for 2 ppbv of the reduction in monthly mean O3 for August 2008.".

In addition to grouping the data by wind directions, we added new analysis in which ozone measurements were grouped by other meteorological parameters: temperature, RH, and wind speed. A new figure was added (Figure 5) and we added the following paragraph (pg 11, line 22 – pg 30):

"Figure 5 presents ozone observations in August 2006-2008 as a function of other meteorological variables (temperature, RH, and wind speed). Each of the meteorological variables has similar ranges for Augusts of the three years, except for the lack of high wind speed sector (> 4 m/s) in August 2008 (to be discussed below). For each of the sectors of temperature, RH, and wind speed shown in Figure 5, mean O3 levels of Augusts 2006 and 2007 were always higher compared with August 2008. The differences tend to be larger at higher temperature and lower RH, which are typically favorable meteorological conditions for ozone pollution. This suggests that meteorology cannot be the only factor contributing to the reductions in O3 in August 2008."

What were the wind speeds in August in 2007 and 2008?

Wind speeds were slightly lower in 2008. We added discussion of wind speeds in the text (pg 12, line 1-7):

"Mean daytime wind speed was 1.3 m/s in August 2008, slightly lower than that of 1.7

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m/s in August 2006 and 2007. For SSW-SW-S-SE winds, mean speed in the afternoon was 1.6 m/s in August 2008 as compared to 2.3 m/s in August 2007. If slower south-westerly winds could be interpreted as indicating slower and less efficient transport of pollution from the Beijing urban region, this in combination with reductions in urban pollutions during the Olympics offers a plausible explanation for lower concentrations of O3 and other pollutants observed at Miyun in August 2008."

. . .whether the estimated emission reductions are the same if CO or NOy serves as a reference.

The lifetime of SO2 is a function of meteorological conditions instead of emissions or SO2 concentrations. We thus assume that the SO2 lifetime would be comparable for the same meteorological conditions, represented by winds, temperature and RH which were the only meteorological parameters available for our study. Given similar SO2 lifetime, the concentration changes in SO2 can be attributed to changes in SO2 emissions. We chose SO2 as the reference in order to minimize the impact of background concentrations (i.e., absent of local emissions) on our analysis. We did the analysis using CO or NOy as a reference, as suggested by the reviewer. If we assume the CO and NOy levels sampled in air masses from NW to represent the clean, background concentrations, we reached a similar estimate of emission reductions as the SO2-reference method.

. . . please provide some info. on the time when the control measures in power plants were in place.

The control measures in power plants were in place since June 2008 (S.X. Wang, submitted manuscript, 2009). We clarified in the text (pg 14, line 26-30): "The flue gas desulphurization (FGD) equipment installed on power plants in Beijing and mandated to operate at full capacity since Jun 2008 (Wang et al., submitted manuscript). . ."

. . . on emission reduction of SO2, NOx, VOC, and CO during the Olympics: Please provide some info. on how these estimates are obtained.

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We added clarification in the text (pg 15, line 11-15): “Researchers at Tsinghua University conducted a detailed bottom-up study of Beijing emissions during the Olympics period based on roadside traffic monitoring, emission measurements at the smoke stacks of selected power plants, statistics on industrial output reductions and plant closures, and other information on activity levels and emission factors (Wang et al., submitted manuscript).”

. . . the model simulation using reduced emission led to the degraded result for primary pollutant (CO and NOy) in the polluted period in the first week of August, any explanation for these?

This is likely related to random errors in the model (dynamics, meteorology, emissions, etc).

Interactive comment on Atmos. Chem. Phys. Discuss., 9, 9927, 2009.