Atmos. Chem. Phys. Discuss., doi:10.5194/acp-2017-173, 2017
Manuscript under review for journal Atmos. Chem. Phys.
Discussion started: 28 March 2017

Differentiating local and regional sources of Chinese urban air pollution based on effect of Spring Festival

Chuan Wang, Xiao-Feng Huang*, Qiao Zhu, Li-Ming Cao, Bin Zhang, Ling-Yan He

Key Laboratory for Urban Habitat Environmental Science and Technology, School of Environment and Energy, Peking University Shenzhen Graduate School, Shenzhen, 518055, China.

*Corresponding author: huangxf@pku.edu.cn

Abstract: The emission of pollutants is extremely reduced during the annual Chinese Spring Festival (SF) in Shenzhen, China. During the SF, traffic flow drops by ~50% and the industrial plants are almost entirely shut down in Shenzhen. To characterize the variation in ambient air pollutants due to the "Spring Festival effect", various gaseous and particulate pollutants were measured in real time in urban Shenzhen over three consecutive winters (2014–2016). The results indicate that the concentrations of NOx, volatile organic compounds (VOCs), black carbon (BC), primary organic aerosols, chloride, and nitrate in submicron aerosols decrease by 50%–80% during the SF period relative to the non-Spring Festival periods, regardless of meteorological conditions, which suggests that these pollutants are mostly emitted or secondarily formed from urban local emissions. The concentration decreasing of regional pollutants or species emitted from natural sources, however, is found to be much less, especially for bulk $PM_{2.5}$ (–24%) and O_3 (6%). More detailed analysis of the Spring Festival effect reveals an urgent need to reduce emissions of SO_2 and VOCs on a regional scale rather than on an urban scale to reduce urban $PM_{2.5}$ in Shenzhen, which can also produce some use for reference for other megacities in China.

Key words: Spring Festival effect; local emissions; regional pollution; $PM_{2.5}$; ozone

1 Introduction

The rapid economic development and urbanization of China over the recent decades has brought with it the consequence of severe atmospheric pollution, especially in the key economically developed regions, such as the Beijing–Tianjin–Hebei region (Sun et al., 2013, 2015; Guo et al., 2014), the Yangtze River Delta (Huang et al., 2013), and the Pearl River Delta (PRD), as well as their densely populated megacities (Hagler et al., 2006; Zhang et al., 2008; He et al., 2011). Great efforts have been made to determine the sources and formation mechanisms of fine particles ($PM_{2.5}$) in these region. Previous studies indicate that $PM_{2.5}$ forms from primary fine particles and through secondary formation from gaseous precursors (Zhang et al., 2008; Zheng et al., 2009; Huang et al., 2014), and the sources of local production and regional transport are both important (Huang et al., 2014; Huang et al., 2006, 2011; Li et al., 2015).

The causes of air pollution in urban atmosphere in China are particularly complicated, and bring great challenges to management strategies for protecting human health (Parrish and Zhu, 2009). To explore the causes of urban air pollution in China, previous studies have focused on monitoring and comparing the reduction in emissions during special events, such as the 2008 Beijing Olympic Games (Huang et al., 2010), the 2010 Guangzhou Asian Games (Xu et al., 2013), the 2014 Asia Pacific Economic Cooperation conference (APEC) (Chen et al., 2015; Sun et al., 2016; Zhang et al., 2016) and the 2015 China victory day parade (Zhao et al., 2016). During such events, the air quality improved remarkable because of short-term limitations on traffic and industrial activity (Huang et al., 2010; Wang et al., 2010; Xu et al., 2013; Sun et al., 2016; Zhao et al., 2016). However, these limitations were temporary,

non-repeatable measures, so the reported emission reductions cannot be verified. Actually, a spontaneous reduction in emissions occurs every year in China during the Spring Festival (SF), which is the single most important holiday in China. During the week-long holiday (in January or February every year), the urban emission patterns depart significantly from the usual patterns: traffic decreases in the mega cities because most people are not working, and most of the industries, stores, and production sites are closed in the city except for the utilities and industries (e.g., power plants) that cannot be shut down (Qin et al., 2004; Feng et al., 2012; Shi et al., 2014). Tan et al. (2009) reported that the concentrations of NOx, CO, NMHC, SO_2, and PM_{10} were lower in the SF periods than in the non-Spring Festival (NSF) periods in the metropolitan area of Taipei over 1994-2006, while the variation of O_3 was in a reversed trend. Jiang et al. (2015) found that the ambient concentrations of VOCs had a sharp decline by ~60% during the SF in Shijiazhuang.

This study focuses on Shenzhen as a special example to evaluate the effect on urban air pollution of the SF. Shenzhen is in the eastern Pearl River Delta (PRD) and is the fourth largest economic center in China, with a total residential population of over 10 million and a fleet of civilian vehicles of more than 3.1 million (Shenzhen Yearbook of Statistics, 2015). Known as the country's city of most floating population, Shenzhen owns 7.4 million immigrants in 2014, which accounts 70% of the city's total population (Shenzhen Yearbook of Statistics, 2015). During the SF period, over 50% of the residents in Shenzhen are used to travel back to their hometowns (http://sz.gov.cn). It is reported that the traffic flow in Shenzhen during the SF of 2016 (Feb 7–13) was only the half before the SF period (http://sz.gov.cn). Additionally, industrial activities are almost totally suspended in Shenzhen during the SF period. To characterize the air quality during such extreme reductions of anthropogenic

Atmos. Chem. Phys. Discuss., doi:10.5194/acp-2017-173, 2017
Manuscript under review for journal Atmos. Chem. Phys.
Discussion started: 28 March 2017

activities during the SF period in Shenzhen, various air pollutants in Shenzhen urban areas were comprehensively and systematically monitored in real time in winter for three consecutive years (2014–2016). The annual SF in Shenzhen thus provides an excellent spontaneous control experiment for local emissions, which could provide unique and valuable information regarding the sources of urban air pollution.

2 Experimental methods

2.1 Monitoring sites and meteorological conditions

The monitoring site (22°36′N, 113°54′E) was on the roof (20 m above ground level) of an academic building on the campus of Peking University Shenzhen Graduate School (PKUSZ) (Figure S1). No significant anthropogenic emission sources exist nearby. The sampling schedule ran roughly from late January to early March over 2014–2016, which includes the official SF holiday period and the prior and following periods. Our definition of the SF period follows that of the statutory public holiday calendar in China, and it is continuous seven days in each year. While the seven days immediately before or after the holidays are actually the transition periods between the holidays and normal days (called the Tran. periods hereafter), when people begin to move from the city (or their hometowns) to their hometowns (or the city), the typical non-spring festival (NSF) periods are better defined as the 7–14 days close to the SF period (called the NSFT period hereafter, where T indicates time similar). The specific dates and the average meteorological parameters are listed in Table 1, and Figure S2 shows wind rose plots. The data in Table 1 show that the meteorology differs among the SF, NSFT, and Tran. periods. To control for the influence of meteorology on the evaluation of emissions, we selected another 7-day period each year when the meteorology is similar to that of the SF period (called

Atmos. Chem. Phys. Discuss., doi:10.5194/acp-2017-173, 2017
Manuscript under review for journal Atmos. Chem. Phys.
Discussion started: 28 March 2017

the NSFM period hereafter, where M indicates meteorology similar); the detailed parameters are listed in Table 1 and Figure S2. The meteorological data for the SF period are fairly similar to those of the NSFM period, suggesting similar meteorological conditions.

Table 1. Summary of meteorological conditions at sampling site during the SF, NSFT, NSFM and Tran. periods of 2014–2016.

		SF	Tran.	NSFT	NSFM
Data period	2014	Jan 31–Feb 6	Feb 7–Feb 13	Feb 14–Feb 20	Feb 20–Feb 26
	2015	Feb 18–Feb 24	Feb 11–Feb17	Feb 4–Feb10	Jan 24–Jan 30
	2016	Feb 7–Feb 13	Feb 14–Feb 20	Feb 21–Feb 27	Feb 27–Mar 4
Meteorological parameters	Temperature (℃)	19.0±4.7	14.1±5.3	14.1±4.0	18.1±3.8
	RH (%)	68.1 ±17.8	69.3±18.4	64.9±16.7	67.4±14.7
	Wind speed ($m\ s^{-1}$)	0.88 ±0.57	0.81±0.49	0.83±0.48	0.86±0.55
	Dominant wind direction	NW	NW and NE	NW and NE	NW
	Precipitation (mm)	0	0	0	0
	UVA ($W\ m^{-2}$)	5.4±8.5	2.5±4.3	3.8±6.7	5.0±8.0
	UVB ($W\ m^{-2}$)	0.24±0.40	0.11±0.25	0.16±0.32	0.22±0.38

Atmos. Chem. Phys. Discuss., doi:10.5194/acp-2017-173, 2017
Manuscript under review for journal Atmos. Chem. Phys.
Discussion started: 28 March 2017

2.2 Instrumentation

For the ambient sampling in this study, the measuring instruments were placed in a room on the top floor of a four-story teaching building at PKUSZ. A high-sensitivity proton transfer reaction mass spectrometer (PTR–MS) (Ionicon Analytik GmbH, Austria) was used to measure the selected volatile organic compounds (VOCs). The PTR–MS measured a total of 25 masses in the selected ion mode at a time resolution of 30 s. Background checks were done for 30 of every 300 scan cycles with an activated charcoal trap at 360 °C, which can remove VOCs from the ambient air without changing water content. The VOCs reported here (Table S1) may be broadly classified into three categories: oxygenated VOCs [OVOCs: methanol, acetone, methyl ethyl ketone (MEK), acetaldehyde, and acetic acid], aromatics (benzene, toluene, styrene, C8 and C9 aromatics), and three types of tracers [isoprene, acetonitrile, and dimethyl sulfide (DMS)]. The PTR–MS was calibrated every 5 to 7 days by using a TO15 mixture standard (Air Environmental Inc., US) and permeation tubes (Valco Instruments Co. Inc., US) (de Gouw and Warneke, 2007).

An aerodyne high-resolution time-of-flight aerosol mass spectrometer (HR–ToF–AMS) (Aerodyne Research, US) was deployed to measure non-refractory PM_1 (NR-PM_1) (Canagaratna et al., 2007) in the period 2014–2015 with a time resolution of 4 min. An aerosol chemical speciation monitor (ACSM) (Aerodyne Research, US) was used in 2016 with a dynamic resolution of 10 min. The detailed description of the ACSM is available in the recent review (Ng et al., 2011). The HR-ToF-AMS and ACSM were calibrated every month following the standard protocols (Ng et al., 2011; Jayne et al., 2000).

An aethalometer (AE–31) (Magee, US) was used for simultaneous detection of refractory black carbon (BC) with a time resolution of 5 min. In addition, a Scan Mobility Particle Sizer (TSI Inc., US) system was used to determine the particle number size distribution in the size range 15–615 nm (Stokes diameter) with a time resolution of 5 min. The stokes diameters of 15–615 nm is converted to aerodynamic diameters of 22–800 nm, and then $PM_{0.8}$ mass concentration can be calculated with the particle density assumed according to the AMS measurement results of species.

To measure the $PM_{2.5}$ mass concentration, we used a Thermo Scientific TEOM 1405–D monitor. The trace-gas instruments included a 43i sulfur dioxide (SO_2) analyzer, a 42i nitric oxide (NO)–nitrogen dioxide (NO_2)–nitrogen oxide (NOx) analyzer, a 49i ozone (O_3) analyzer, and a 48i carbon monoxide (CO) analyzer (Thermo Scientific, US). A meteorological station, also located on the roof of the same building, measured the main meteorological parameters, such as temperature, relative humidity, and wind speed (see Table 1).

3 Results and Discussion

3.1 The NSF–SF differences for major air pollutants

The results of observations from 2014 to 2016 appear in Figures S3–S5. Figure 1 shows the averaged percent changes in the concentrations of major air pollutants of the SF periods relative to the two NSF periods and Tran. period over 2014–2016. The compounds m/z 44 and m/z 57 are the tracer of oxygenated organic aerosol and the tracer of primary hydrocarbon organic aerosol (Zhang et al., 2005), respectively, which are organic fragments in the AMS measurements. The notation O_3–8h refers to the average maximum O_3 concentration over a continuous diurnal 8 h and $PM_{0.8–2.5}$ refers to the difference

Atmos. Chem. Phys. Discuss., doi:10.5194/acp-2017-173, 2017
Manuscript under review for journal Atmos. Chem. Phys.
Discussion started: 28 March 2017

between the concentrations of $PM_{2.5}$ and $PM_{0.8}$.

We can divide these air pollutants into three classes based on their percent changes: The group with the largest drop (hereinafter called "LD") in concentration includes the aromatics (−50% to −88% for the various species, see Figure S6), OVOCs (−40% to −85% for the various species, see Figure S6), NOx, chloride (Chl), nitrate (NO_3^-), BC, and m/z 57. The concentrations of these pollutants all decrease by over 50% during the SF period compared with both the NSF periods. Apparently, the dominant sources for most of these pollutants are primary local emissions, such as combustion sources for BC, m/z 57, and NOx (Zhang et al., 2005; Kuhlbusch et al., 1998; Lan et al., 2011), and vehicle, industrial and solvent use for aromatics (Liu et al., 2008). As detailed in the following section, the diurnal patterns and relationships with respect to wind speed further confirm the sources of these pollutants. The dramatic decrease in the ambient concentrations of these species is consistent with reduction in local anthropogenic activities in Shenzhen during the SF period. The SF causes a 50% decrease in urban traffic and temporarily closing of almost all local industrial plants. The nitrate and chloride measured by AMS or ACSM are actually ammonium nitrate (NH_4NO_3) and ammonium chloride (NH_4Cl), which are typical secondary air pollutants. These are thought to form via reversible phase equilibria with gaseous ammonia (NH_3), nitric acid (HNO_3), and hydrochloric acid (HCl) (He et al., 2011; Huang et al., 2011; Zhang et al., 2007). Typically, the formation of NH_4NO_3 from NOx and the reaction between HCl and NH_3 occur quickly in the atmosphere (Stelson and Seinfeld, 1982; Baek et al., 2004), suggesting that the concentrations of NO_3^- and Chl in winter in Shenzhen depend largely on the emission of precursors such as HCl and NOx. Therefore, the significant decline in the ambient concentrations of NO_3^- and Chl during the SF period and indicates that their precursors also have local

origins, similar to the case for primary pollutants (this is also supported by the discussion in the following sections). The huge decline in the ambient concentration of OVOCs during the SF period shows that the source of these pollutants is (i) mainly from local emissions, including vehicle and industrial emissions (Schauer et al., 1999; Singh et al., 2001) and (ii) from secondary reactions involving local primary VOCs (Liu et al., 2015). Thus, in the LD group, the significant reduction in local sources of pollutants strongly impacts the concentration of air pollutants.

The pollutants in the next group undergo a medium drop in concentration during the SF period (hereinafter called "MD"). These are $PM_{2.5}$, NR–PM_1, $PM_{0.8}$, organic aerosol, m/z 44, sulfate (SO_4^{2-}), ammonium (NH_4^+), isoprene, acetonitrile, DMS, and carbon monoxide (CO), and their percent change varies from −20% to −55% when comparing the SF periods to the NSFT and NSFM periods. The species in this group are either typical secondary regional air pollutants, such as CO, which has a long lifetime and is a tracer for combustion sources, acetonitrile from rural biomass burning (de Gouw et al., 2003; Le Breton et al., 2013), m/z 44 representing secondary organic aerosols, SO_4^{2-} from SO_2 oxidation (He et al., 2011; Huang et al., 2011), or typical tracers for natural sources, such as isoprene from vegetation (Guenther et al., 1995) and DMS from marine source (Dacey and Wakeham, 1986). In winter, the northeastern monsoon prevails in the PRD and transports significant amounts of various air pollutants from the northern inland, increasing air pollution of the PRD to the highest levels through the year (Huang et al., 2014). In particular, the small drop in CO concentration during the SF period puts it in this group and indicates that the contribution to regional air pollution does not decrease significantly during the SF period. Note that, the significant declines of the concentrations of isoprene and DMS imply that they have anthropogenic sources, which will be supported in the following

sections. The other air pollutants in this group are the reflection of the overall effect of the reduction of relevant air pollutants: OA is the whole of the two types of organic aerosol represented by m/z 44 and m/z 57, NH_4^+ is represented by SO_4^{2-}, NO_3^- and Chl, and NR–PM_1 is the sum of all species measured by AMS or ACSM (their average chemical compositions during different periods are shown in Figure S3–S5).

The group of pollutants with smallest decrease in concentration (hereinafter called "SD") includes SO_2, $PM_{0.8–2.5}$, and O_3. The magnitude of the average percent change is less than 20% relative to the two NSF periods. The average concentration of SO_2 was only 2.8 ppbv in Shenzhen in 2015 (http://www.szhec.gov.cn/), which is much lower than that in Beijing (4.7 ppbv) and elsewhere in China (http://www.zhb.gov.cn/). This result is partly attributed to the negligible coal consumption in Shenzhen, which instead relies mainly on natural gas and liquefied petroleum gas (Shenzhen Yearbook of Statistics, 2015). The emission inventory indicates that international marine container vessels are the dominant source of SO_2 in Shenzhen (Wang et al., 2009), and according to official statistics, the Shenzhen port piloted 401, 568, and 521 ships during the SF period in the years 2014–2016, respectively, which is quite similar to numbers for the NSF periods (http://www.pilot.com.cn). Obviously, the small decrease of SO_2 is reasonably related with the stable ship emissions during the SF periods. The small decline of $PM_{0.8–2.5}$ during the SF period suggests that the reduction of more aged particles of lager sizes in $PM_{2.5}$ is much lower than fresher particles of smaller size. This can be also confirmed by particle number concentration (PNC) measurement by SMPS, as shown in Figure 2. The largest difference of the PNC between the SF and NSFM periods exists mainly in a smaller size range (20–40 nm), which is recognized as the nucleation mode or second Aitken mode that represents

Atmos. Chem. Phys. Discuss., doi:10.5194/acp-2017-173, 2017
Manuscript under review for journal Atmos. Chem. Phys.
Discussion started: 28 March 2017

fresh combustion emission (Ferin et al., 1990). Contrary to other pollutants, the concentrations of O_3, present small increasing during the SF period (except a little decline when comparing O_3–8h with the NSFM period), which could be attributed to the different drop rates for O_3 precursor species, i.e. NOx and VOCs (Qin et al., 2004), and will be discussed in more detail in section 3.2.

The results for the various species during the NSFT and NSFM periods are consistent, which suggest that meteorology has only a small impact on their concentrations. This means that the strong decrease in the concentrations of air pollutants in group LD and MD is mainly due to the abatement of local sources. The larger decline in the SF period when compared to NSFT than to NSFM is associated with the lower temperature and stronger winds from the polluted northwest inland of the PRD during the NSFT period. In addition, the effect of the SF on the concentrations of the various species is almost identical each year (see Figure S7), which further confirms that the pollutant concentrations are determined primarily by the activity of the sources. In Figure 1, the percent changes of pollutants of the SF periods relative to the Tran. periods are also presented, and it is found that the three-group classification defined above is also applicable, while the decrease levels are lower. For example, the average decrease percent of Group LD for the Tran. period case is 61%, while those for the NSFT and NSFM cases are 71% and 63%, respectively. This result is consistent with the fact that the SF travel of people occurred mostly during the seven days before and after the SF holidays (http://sz.gov.cn), and thus the city became much emptier even in the Tran. periods. In order to make a deeper and valid comparison for revealing the SF effect, the following discussion will only take the NSFM periods and SF periods for comparative analysis due to their more similar meteorology.

Atmos. Chem. Phys. Discuss., doi:10.5194/acp-2017-173, 2017
Manuscript under review for journal Atmos. Chem. Phys.
Discussion started: 28 March 2017

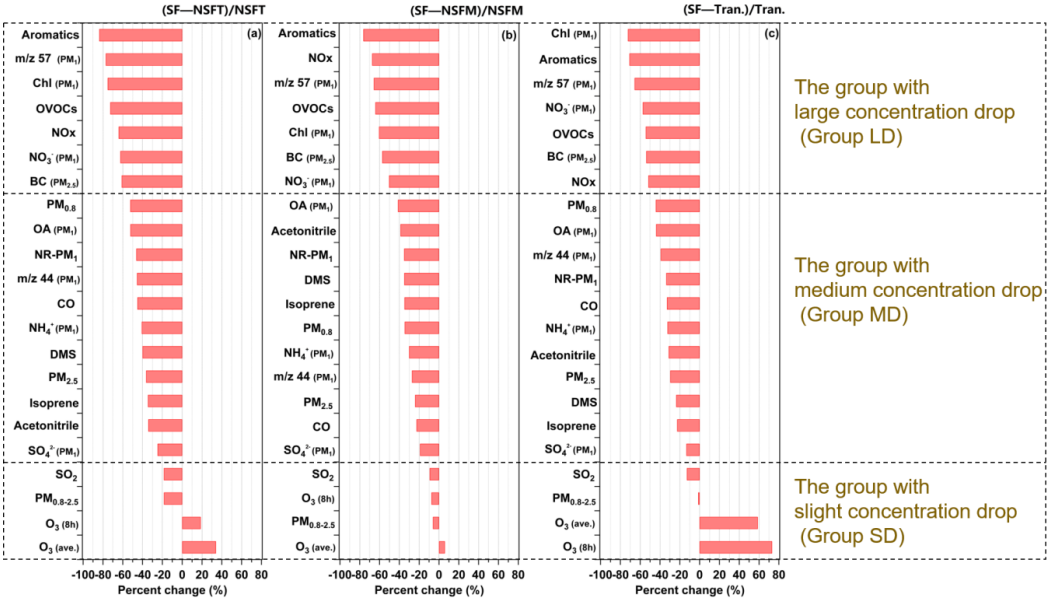

Figure 1. Percent change in concentrations of major air pollutants during the SF period relative to (a) Tran., (b) NSFT and (c) NSFM periods averaged over 2014–2016.

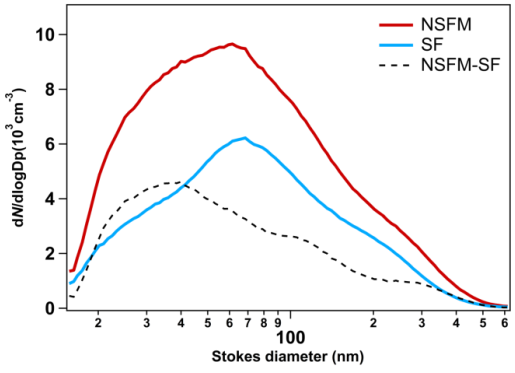

Figure 2. Distribution of particle number concentration in the 15–615 nm size range during the SF and NSFM periods.

Atmos. Chem. Phys. Discuss., doi:10.5194/acp-2017-173, 2017
Manuscript under review for journal Atmos. Chem. Phys.
Discussion started: 28 March 2017

3.2 The diurnal variation of major air pollutants

As shown in Figure 3, the diurnal cycles of all LD pollutants (except for the OVOCs) reveal significant peaks in concentration around 8–9 am in the NSFM period, which is attributed to the low planetary boundary layer (PBL) in the morning and local rush hour traffic emissions. The evening rush hour peak, however, is not apparent for all the species, which is attributed to the higher ambient temperature and thus the higher PBL at that time than in the morning. During the SF period, the concentrations of all pollutants are far lower over the entire day. In particular, the rush-hour peaks become much smaller or disappear altogether, which is consistent with the large reduction in local vehicle emissions during the SF period. Although the sources of Chl remained uncertain in previous studies (Huang et al., 2011; Aiken et al., 2008), the maximal reduction (80%) in this pollutant during the morning rush hour during the SF period implies that local traffic emissions account for a significantly fraction of this pollutant in Shenzhen (Figure 3E). Contrary to other species in this group, the concentration of OVOCs is high in the daytime and peaks in the morning after the morning rush hour time during the NSFM period (Figure 3D), suggesting that photochemical production and/or daytime industrial activities may be important sources of OVOCs. The concentrations of different aromatics and OVOCs usually follow similar diurnal variations (Figure S8).

The diurnal variations of the MD pollutants are relatively smooth except for the two natural VOCs (isoprene and DMS; see Figures 3L and 3M), which indicates that these pollutants come from regional sources and are dispersed more uniformly over a larger scale. The apparent difference of the diurnal variations of those anthropogenic air pollutants between the SF and NSFM periods also exists in the rush hours (except for acetonitrile; Figure 3J), however, the reduction in local sources has a relatively

weak effect on the overall concentrations of these pollutants. Acetonitrile, which is a tracer of biomass burning, is more concentrated during the daytime and its peak concentration occurs after the rush hours during the NSFM period (Figure 3J), which is similar to the result obtained for OVOCs and may be attributed to the influence of daytime anthropogenic activities, for example, industrial biomass boilers. Isoprene is primarily emitted by vegetation as a function of light and temperature, so the concentration of this pollutant goes through a broad peak that spans the daytime hours during both the NSFM and SF periods. The percent change in isoprene concentration between the SF and NSFM periods is approximately −40% (Figure 3M), despite the NSFM and SF periods having similar temperature and solar radiation, which implies that the contribution of anthropogenic sources to isoprene cannot be overlooked in Shenzhen. Many studies have reported isoprene from vehicle exhaust, especially in cold seasons (Barletta et al., 2005; Borbon et al., 2001). DMS is reported to be a marine tracer (Dacey et al., 1986), its peak concentration occurs in the morning during both the NSFM and SF periods (Figure 3L), which is presumably related to the minimal PBL. The concentration of DMS decreases by 30%–50% during the SF period, which reflects the reduced DMS emissions from anthropogenic sources. As reported in the literature, industrial activities can make significant emissions of DMS (Schafer et al., 2010).

The diurnal variations of $PM_{0.8–2.5}$, SO_2 and O_3 demonstrated more similar concentrations and trends in the SF and NSFM periods, respectively (Figure 3T–3V). For $PM_{0.8–2.5}$, a small difference is found in the afternoon, which is supposed to be a result of more aged larger particles formed through stronger photochemical reactions during the NSFM period. Though, slight differences appear in SO_2 concentration, mainly during the nighttime when the PBL is low. These data suggest a minor role of

local near-ground SO_2 sources, such as vehicles. Although the daytime peak concentration of O_3 during the NSFM period is slightly greater than that during the SF period, this trend reverses from the evening to the midmorning hours. Similar phenomena have also been observed in other emission-reduction studies of urban areas (i.e., emissions are greater on holidays than on non-holidays) (Qin et al., 2004; Tan et al., 2009). In addition, emissions were higher during the 2008 Beijing Olympic Games (Chou et al., 2011), during which strict controls were imposed. A recent study reported that, in most of the PRD region, O_3 formation is VOC limited in the morning and becomes NOx limited during peak O_3 hours (Li et al., 2013). The concentrations of NOx and VOCs decrease gradually from 8 to 12 h during the SF period whereas the concentration ratio TVOC/NOx increases (see Figure 3H, where TVOC concentration is the sum of aromatic and OVOC concentrations). Thus, the lack of NOx at noon during the SF period hinders the generation of O_3. At other hours in the NSFM period, a higher NO concentration destroys O_3, implying that the oxidation reaction with NO may produce a titration effect (Qin et al., 2004; Tan et al., 2009). As a result, although the reduction in emissions of urban anthropogenic sources leads to a significant decline of NOx and VOCs, this reduction does not mitigate the average ambient O_3 concentration, which implies that the concentration ratio VOC/NOx plays an important role in controlling O_3 concentration.

Atmos. Chem. Phys. Discuss., doi:10.5194/acp-2017-173, 2017
Manuscript under review for journal Atmos. Chem. Phys.
Discussion started: 28 March 2017

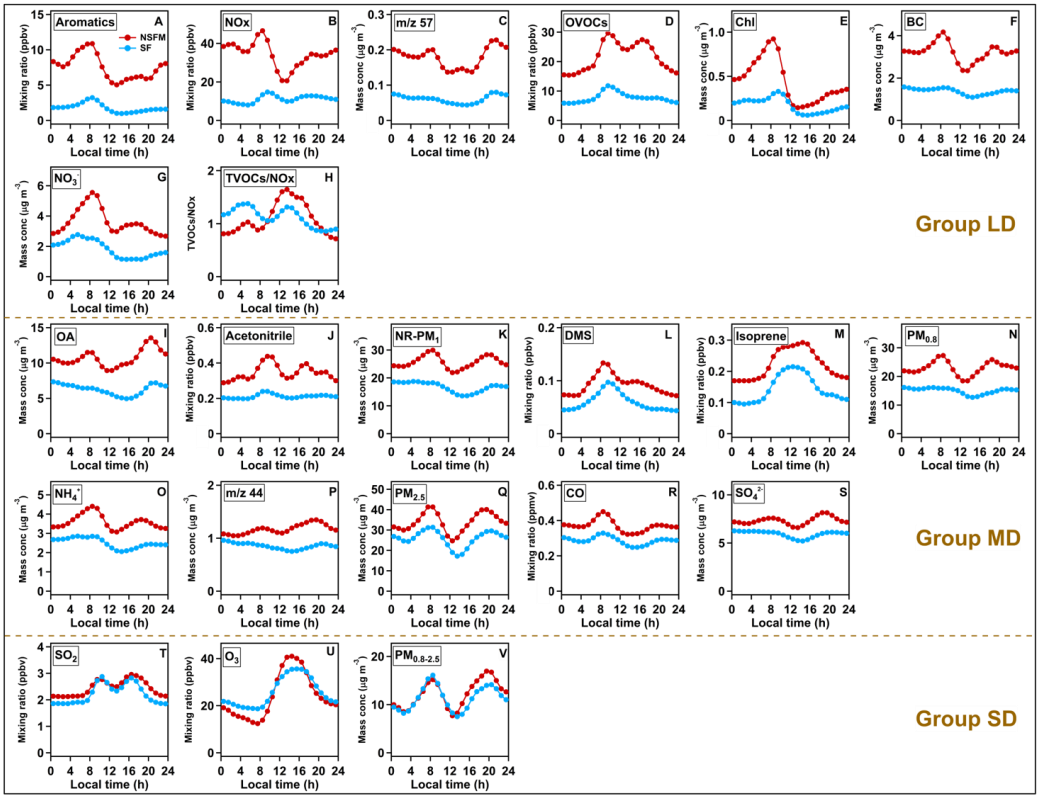

Figure 3. Diurnal variations in concentrations of major air pollutants at PKUSZ site over the SF (blue dots) and NSFM (red dots) periods.

3.3 Influence of wind on observed air pollutants

Wind plays a crucial role in the dilution and transport of air pollution. The wind field is essentially the same during the SF and NSFM periods. In general, the concentrations of LD air pollutants depend strongly on wind speed during the NSFM period, whereas this dependence becomes much weaker during the SF period (Figure 4). The difference in the concentration of LD air pollutants (including various aromatics and OVOCs, see Figure S9) between the NSFM and SF periods is maximal (50%–80%) under conditions of low wind speeds (<1 m/s) because local pollution can more easily

accumulate under these conditions. These results confirm that the concentration of air pollutants from local sources is strongly reduced during in the SF period.

Compared with the LD pollutants, the concentrations of CO, SO_4^{2-}, m/z 44, isoprene, DMS, and acetonitrile do not vary significantly with wind speed during the NSFM period, providing further evidence that these pollutants come from regional or natural sources and are consequently more evenly distributed in the atmosphere.

In the Group SD, SO_2 is generally little influenced by wind speed during the SF period, while some higher concentrations appeared under low wind speeds during the NSFM period, indicating again small contribution of urban local sources to SO_2. The fluctuation of $PM_{0.8–2.5}$ both in the SF and NSFM periods does not reveal a clear relationship with wind speed, suggesting again it is not a typical locally emitted air pollutant. The variations of O_3–8h display the opposite trend to other air pollutants both in the SF and NSFM periods, growing smoothly as wind speed increases, which could be possibly attributed to more regional transport and/or the higher VOCs/NOx ratio under high wind speeds (Figure 4H). Note that, when the proportion of regional transport relative to local emission becomes bigger under higher wind speeds, the concentrations of NO_3^-, SO_4^{2-}, m/z 44, $PM_{0.8–2.5}$, and O_3–8h are even slightly higher in the SF period than in the NSFM period, implying that regional photochemical production during the SF period is not weakened.

Atmos. Chem. Phys. Discuss., doi:10.5194/acp-2017-173, 2017
Manuscript under review for journal Atmos. Chem. Phys.
Discussion started: 28 March 2017

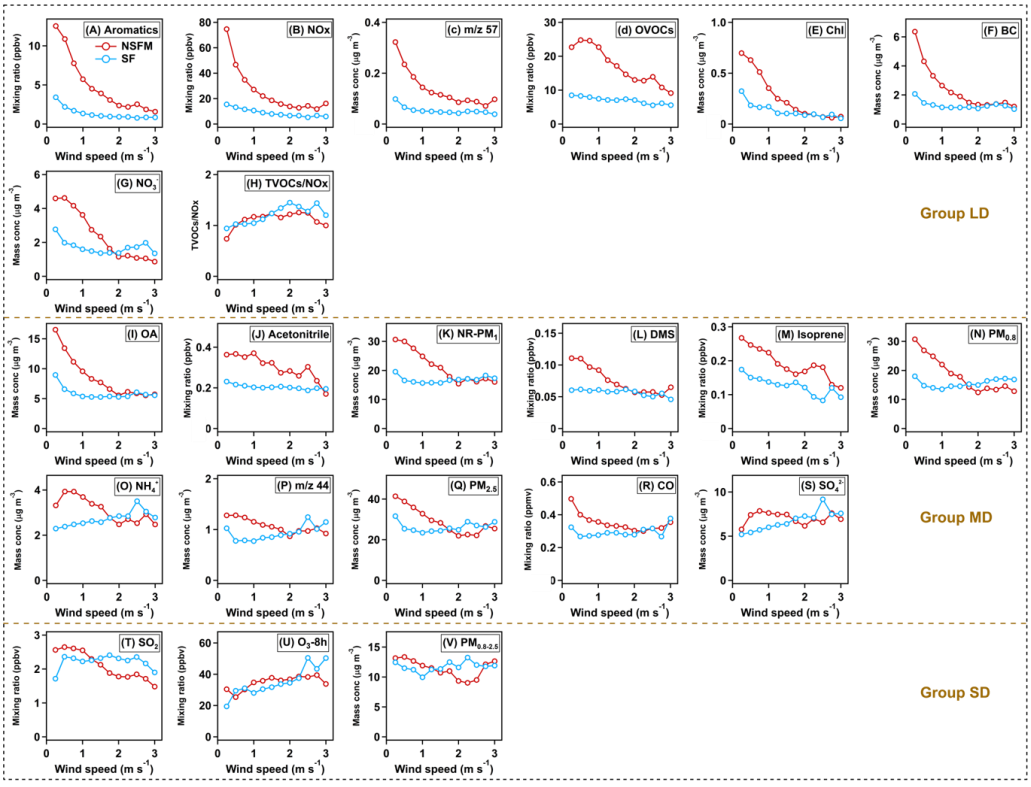

Figure 4. Concentrations of major air pollutants as a function of wind speed during the SF and NSFM periods.

3.4 Emission ratio analysis

Several groups of special correlations were applied to analyze the source characteristics of air pollutants in Figure 5. CO and BC are both products of incomplete combustion (Subramanian et al., 2010), but gaseous CO can travel farther because of its longer atmospheric lifetime (approximately a month for CO vs a week for BC) (Khalil et al., 1990; Ogren et al., 1983). As shown in Figure 5A, the correlation coefficient and slope between BC and CO during the NSFM period (r^2 = 0.56, slope = 13.9)

is greater than during the SF period (r^2 = 0.31, slope = 3.9), suggesting that local combustion sources make a much greater contribution during the NSFM period, but decline significantly during the SF period (He et al., 2011). The concentrations of two natural species, isoprene and DMS, are not correlated with CO during the SF, whereas their correlation with CO is non-negligible during the NSFM period (Figures 5B and 5C), suggesting again that these pollutants have an anthropogenic source during the NSFM period.

The toluene/benzene ratio can be used to estimate the contribution of traffic emissions (Schneider et al., 2005). Generally, a value of 1.2–3 is found to be characteristic of vehicular emission in many urban areas (Nelson et al., 1984; Wang et al., 2002; Araizaga et al., 2013). The lower ratio of toluene to benzene (ave.=2.6) in the SF period suggests that the dominant source is vehicle emission. This ratio in the NSFM period, however, is much higher (ave.=7.7), indicating more complicated sources of VOCs like huge amount of toluene solvent usage in industrial activities in PRD (Barletta et al., 2005, 2008; Chan et al., 2006). This finding is well consistent with the temporary closure of industrial plants in the SF period, which leads to little toluene emission.

Atmos. Chem. Phys. Discuss., doi:10.5194/acp-2017-173, 2017
Manuscript under review for journal Atmos. Chem. Phys.
Discussion started: 28 March 2017

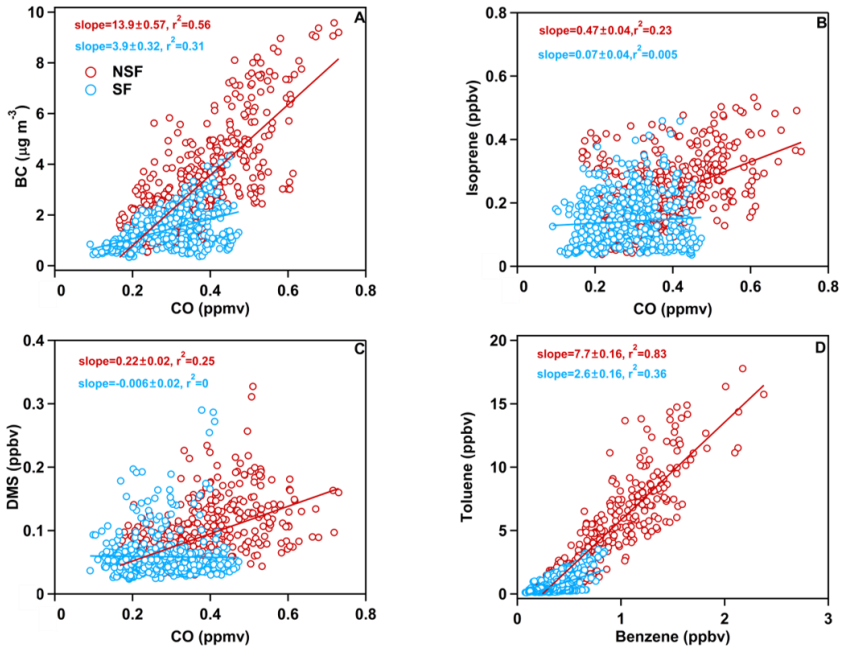

Figure 5. Correlation between air pollutants (A) BC and CO (B) isoprene and CO, (C) DMS and CO, and (D) toluene and benzene during the SF (blue circles) and the NSFM (red circles) periods.

3.5 Conclusions

This study uses the SF in Shenzhen to investigate how the urban air quality reacts to significant, temporary reductions in emission. During the winters of 2014 to 2016, the air quality was observed continuously at Peking University Shenzhen Graduate School, from which we obtained the percent change in the concentrations of various air pollutants during the SF periods with respect to the comparable NSF periods. The analysis of these data shows that, despite meteorological variations, the Spring Festival clearly and consistently influences the urban concentrations of various air pollutants. The air pollutants can be divided into three groups: the large-decrease (LD) pollutants are those with

a percent change in concentration of −50% to −80% during the SF period and include aromatics, NOx, m/z 57, OVOCs, Chl, BC, and NO_3^-. These results are consistent with the variation in urban emission sources during the SF, suggesting that these pollutants are mostly directly emitted or formed from secondary reactions between locally emitted pollutants. The medium-decrease (MD) pollutants are $PM_{2.5}$, NR–PM_1, $PM_{0.8}$, organic aerosol, m/z 44, SO_4^{2-}, NH_4^+, isoprene, acetonitrile, DMS, and CO; the concentrations of these pollutants decrease by 20% to 55% during the SF, which indicates that the extreme reduction in urban emissions during the SF period has limited effect on regional or natural air pollutants. These results provide further evidence that the origins of these pollutants are primarily regional or natural. Finally, the slight-decrease (SD) pollutants include SO_2, $PM_{0.8–2.5}$, and O_3. The average percent change in the concentrations of these pollutants during the SF period is less than 20%, which indicates that a significant reduction in urban emissions does not significantly affect their concentration. Of particular interest is the origin of $PM_{0.8–2.5}$, which is almost completely regional. In addition, it is found that the concentration of O_3–8h correlates strongly with the concentration ratio TVOC/NOx.

The results of this study show that the extreme reductions in urban emissions of Shenzhen only affects the concentration of smaller fresh particles, such as $PM_{0.8}$, whereas the reduction of $PM_{2.5}$ is only slightly affected because of the weak influence on aged, larger particles such as $PM_{0.8–2.5}$. The concentrations of SO_4^{2-} and secondary organic aerosols are hardly unaffected by local reductions in emissions. Therefore, reducing the emissions of SO_2 and VOCs on a regional scale is critical for reducing their concentrations and achieving the goal of reducing concentrations of $PM_{2.5}$, at least for South China. On the other hand, O_3 has recently become an increasingly important air pollutant in

China, especially in the PRD. However, the significant reduction of the concentration of its precursors (NOx and VOCs) during the SF period does not lead to significant reduction of the O_3 concentration because of the concentration ratio VOCs/NOx remains unchanged. Consequently, further investigations are required to control not only the emissions of VOCs and NOx but also their concentration ratio.

Acknowledgements

This work was supported by the National Natural Science Foundation of China (U1301234 & 41622304), the Ministry of Science and Technology of China (2014BAC21B03), and the Science and Technology Plan of Shenzhen Municipality.

Reference

Aiken, A. C., Decarlo, P. F., Kroll, J. H., Worsnop, D. R., Huffman, J. A., Docherty, K. S., Ulbrich, I. M., Mohr, C., Kimmel, J. R., Sueper, D., Sun, Y., Zhang, Q., Trimborn, A., Northway, M., Ziemann, P. J., Canagaratna, M. R., Onasch, T. B., Alfarra, M. R., Prevot, A. S. H., Dommen, J., Duplissy, J., Metzger, A., Baltensperger, U., and Jimenez, J. L.: O/C and OM/OC ratios of primary, secondary, and ambient organic aerosols with high-resolution time-of-flight aerosol mass spectrometry, Environ. Sci. Technol., 42, 4478-4485, doi:10.1021/es703009q, 2008.

Araizaga, A. E., Mancilla, Y., and Mendoza, A.: Volatile Organic Compound Emissions from Light-Duty Vehicles in Monterrey, Mexico: a Tunnel Study, Int. J. Environ. Res., 7, 277-292, 2013.

Baek, B. H., Aneja, V. P., and Tong, Q. S.: Chemical coupling between ammonia, acid gases, and fine particles, Environ. Pollut., 129, 89-98, doi:10.1016/j.envpol.2003.09.022, 2004.

Barletta, B., Meinardi, S., Rowland, F. S., Chan, C. Y., Wang, X. M., Zou, S. C., Chan, L. Y., and Blake, D. R.: Volatile organic compounds in 43 Chinese cities, Atmos. Environ., 39, 5979-5990, doi:10.1016/j.atmonsenv.2005.06.029, 2005.

Barletta, B., Meinardi, S., Simpson, I. J., Zou, S. C., Rowland, F. S., and Blake, D. R.: Ambient mixing ratios of nonmethane hydrocarbons (NMHCs) in two major urban centers of the Pearl River Delta (PRD) region: Guangzhou and Dongguan, Atmos. Environ., 42, 4393-4408, doi:10.1016/j.atmosenv.2008.01.028, 2008.

Borbon, A., Fontaine, H., Veillerot, M., Locoge, N., Galloo, J. C., and Guillermo, R.: An investigation into the traffic-related fraction of isoprene at an urban location, Atmos. Environ., 35, 3749-3760, doi:10.1016/S1352-2310(01)00170-4, 2001.

Canagaratna, M. R., Jayne, J. T., Jimenez, J. L., Allan, J. D., Alfarra, M. R., Zhang, Q., Onasch, T. B., Drewnick, F., Coe, H., Middlebrook, A., Delia, A., Williams, L. R., Trimborn, A. M., Northway, M. J., DeCarlo, P. F., Kolb, C. E., Davidovits, P., and Worsnop, D. R.: Chemical and microphysical characterization of ambient aerosols with the aerodyne aerosol mass spectrometer, Mass Spectrom. Rev., 26, 185-222, doi:10.1002/mas.20115, 2007.

Chan, L. Y., Chu, K. W., Zou, S. C., Chan, C. Y., Wang, X. M., Barletta, B., Blake, D. R., Guo, H., and Tsai, W. Y.: Characteristics of nonmethane hydrocarbons (NMHCs) in industrial, industrial-urban, and industrial-suburban atmospheres of the Pearl River Delta (PRD) region of south China, J. Geophys. Res.-Atmos., 111(D11), D11304, doi:10.1029/2005jd006481, 2006.

Chen, C., Sun, Y. L., Xu, W. Q., Du, W., Zhou, L. B., Han, T. T., Wang, Q. Q., Fu, P. Q., Wang, Z. F., Gao, Z. Q., Zhang, Q., and Worsnop, D. R.: Characteristics and sources of submicron aerosols above the urban canopy (260m) in Beijing, China, during the 2014 APEC summit, Atmos. Chem. Phys., 15, 12879–12895, doi:10.5194/acp-15-12879-2015, 2015.

Chou, C. C. K., Tsai, C. Y., Chang, C. C., Lin, P. H., Liu, S. C., and Zhu, T.: Photochemical production of ozone in Beijing during the 2008 Olympic Games, Atmos. Chem. Phys., 11, 9825-9837, doi:10.5194/acp-11-9825-2011, 2011.

Dacey, J. W. H., and Wakeham, S. G.: Oceanic Dimethylsulfide - Production during Zooplankton Grazing on Phytoplankton, Science, 233, 1314-1316, doi:10.1126/science.233.4770.1314, 1986.

de Gouw, J. A., Warneke, C., Parrish, D. D., Holloway, J. S., Trainer, M., and Fehsenfeld, F. C.: Emission sources and ocean uptake of acetonitrile (CH3CN) in the atmosphere, J. Geophys. Res.-Atmos., 108, doi:10.1029/2002jd002897, 2003.

de Gouw, J., and Warneke, C.: Measurements of volatile organic compounds in the earths atmosphere using proton-transfer-reaction mass spectrometry, Mass Spectrom. Rev., 26, 223-257,

doi:10.1002/mas.20119, 2007.

Feng, J. L., Sun, P., Hu, X. L., Zhao, W., Wu, M. H., and Fu, J. M.: The chemical composition and sources of PM2.5 during the 2009 Chinese New Year's holiday in Shanghai, Atmos. Res., 118, 435-444, doi:10.1016/j.atmosres.2012.08.012, 2012.

Ferin, J., Oberdorster, G., Penney, D. P., Soderholm, S. C., Gelein, R., and Piper, H. C.: Increased Pulmonary Toxicity of Ultrafine Particles .1. Particle Clearance, Translocation, Morphology, J. Aerosol Sci., 21, 381-384, doi:10.1016/0021-8502(90)90064-5, 1990.

Guenther, A., Hewitt, C. N., Erickson, D., Fall, R., Geron, C., Graedel, T., Harley, P., Klinger, L., Lerdau, M., Mckay, W. A., Pierce, T., Scholes, B., Steinbrecher, R., Tallamraju, R., Taylor, J., and Zimmerman, P.: A Global-Model Of Natural Volatile Organic-Compound Emissions, J. Geophys. Res.-Atmos., 100, 8873-8892, doi:10.1029/94jd02950, 1995.

Guo, S., Hu, M., Zamora, M. L., Peng, J. F., Shang, D. J., Zheng, J., Du, Z. F., Wu, Z., Shao, M., Zeng, L. M., Molina, M. J., and Zhang, R. Y.: Elucidating severe urban haze formation in China, P. Natl. Acad. Sci. USA, 111, 17373-17378, doi:10.1073/pnas.1419604111, 2014.

Hagler, G. S., Bergin, M. H., Salmon, L. G., Yu, J. Z., Wan, E. C. H., Zheng, M., Zeng, L. M., Kiang, C. S., Zhang, Y. H., Lau, A. K. H., and Schauer, J. J.: Source areas and chemical composition of fine particulate matter in the Pearl River Delta region of China, Atmos. Environ., 40, 3802-3815, doi:10.1016/j.atmosenv.2006.02.032, 2006.

He, L. Y., Huang, X. F., Xue, L., Hu, M., Lin, Y., Zheng, J., Zhang, R. Y., and Zhang, Y. H.: Submicron aerosol analysis and organic source apportionment in an urban atmosphere in Pearl River Delta of China using high-resolution aerosol mass spectrometry, J. Geophys. Res.-Atmos., 116, D12304, doi:10.1029/2010jd014566, 2011.

Huang, R. J., Zhang, Y. L., Bozzetti, C., Ho, K. F., Cao, J. J., Han, Y. M., Daellenbach, K. R., Slowik, J. G., Platt, S. M., Canonaco, F., Zotter, P., Wolf, R., Pieber, S. M., Bruns, E. A., Crippa, M., Ciarelli, G., Piazzalunga, A., Schwikowski, M., Abbaszade, G., Schnelle-Kreis, J., Zimmermann, R., An, Z. S., Szidat, S., Baltensperger, U., El Haddad, I., and Prevot, A. S. H.: High secondary aerosol contribution to particulate pollution during haze events in China, Nature, 514, 218-222, doi:10.1038/nature13774, 2014.

Huang, X. F., Yu, J. Z., He, L. Y., and Yuan, Z. B.: Water-soluble organic carbon and oxalate in aerosols at a coastal urban site in China: Size distribution characteristics, sources, and formation mechanisms,

J. Geophys. Res.-Atmos., 111, D22212, doi:10.1029/2006jd007408, 2006.

Huang, X. F., He, L. Y., Hu, M., Canagaratna, M. R., Sun, Y., Zhang, Q., Zhu, T., Xue, L., Zeng, L. W., Liu, X. G., Zhang, Y. H., Jayne, J. T., Ng, N. L., and Worsnop, D. R.: Highly time-resolved chemical characterization of atmospheric submicron particles during 2008 Beijing Olympic Games using an Aerodyne High-Resolution Aerosol Mass Spectrometer, Atmos. Chem. Phys., 10, 8933-8945, doi:10.5194/acp-10-8933-2010, 2010.

Huang, X. F., He, L. Y., Hu, M., Canagaratna, M. R., Kroll, J. H., Ng, N. L., Zhang, Y. H., Lin, Y., Xue, L., Sun, T. L., Liu, X. G., Shao, M., Jayne, J. T., and Worsnop, D. R.: Characterization of submicron aerosols at a rural site in Pearl River Delta of China using an Aerodyne High-Resolution Aerosol Mass Spectrometer, Atmos. Chem. Phys., 11, 1865-1877, doi:10.5194/acp-11-1865-2011, 2011.

Huang, X. F., Xue, L., Tian, X. D., Shao, W. W., Sun, T. L., Gong, Z. H., Ju, W. W., Jiang, B., Hu, M., and He, L. Y.: Highly time-resolved carbonaceous aerosol characterization in Yangtze River Delta of China: Composition, mixing state and secondary formation, Atmos. Environ., 64, 200-207, doi:10.1016/j.atmosenv.2012.09.059, 2013.

Huang, X. F., Yun, H., Gong, Z. H., Li, X., He, L., Zhang, Y. H., and Hu, M.: Source apportionment and secondary organic aerosol estimation of PM2.5 in an urban atmosphere in China, Sci. China Earth Sci., 57, 1352-1362, doi:10.1007/s11430-013-4686-2, 2014.

Jayne, J. T., Leard, D. C., Zhang, X. F., Davidovits, P., Smith, K. A., Kolb, C. E., and Worsnop, D. R.: Development of an aerosol mass spectrometer for size and composition analysis of submicron particles, Aerosol Sci. Tech., 33, 49-70, doi:10.1080/027868200410840, 2000.

Jiang, J. B., Jin, W., Yang, L. L., Feng, Y., Chang, Q., Li, Y. Q., and Zhou, J. B.: The Pollution Characteristic of VOCs of Ambient Air in Winter in Shijiazhang, Environmental Monitoring in China, 31, 2015 (in Chinese).

Khalil, M. A. K., and Rasmussen, R. A.: The Global Cycle of Carbon-Monoxide-Trends And Mass Balance, Chemosphere, 20, 227-242, doi: 10.1016/0045-6535(90)90098-E, 1990.

Kuhlbusch, T. A. J.: Black carbon and the carbon cycle, Science, 280, 1903-1904, doi:10.1126/science.280.5371.1903, 1998.

Lan, Z. J., Chen, D. L., Li, X. A., Huang, X. F., He, L. Y., Deng, Y. G., Feng, N., and Hu, M.: Modal characteristics of carbonaceous aerosol size distribution in an urban atmosphere of South China, Atmos. Res., 100, 51-60, doi:10.1016/j.atmosres.2010.12.022, 2011.

Le Breton, M., Bacak, A., Muller, J. B. A., O'Shea, S. J., Xiao, P., Ashfold, M. N. R., Cooke, M. C., Batt, R., Shallcross, D. E., Oram, D. E., Forster, G., Bauguitte, S. J. B., and Percival, C. J.: Airborne hydrogen cyanide measurements using a chemical ionisation mass spectrometer for the plume identification of biomass burning forest fires, Atmos. Chem. Phys., 13, 9217-9232, doi:10.5194/acp-13-9217-2013, 2013.

Li, P. F., Yan, R. C., Yu, S. C., Wang, S., Liu, W. P., and Bao, H. M.: Reinstate regional transport of PM2.5 as a major cause of severe haze in Beijing, P. Natl. Acad. Sci. USA, 112, E2739-E2740, doi:10.1073/pnas.1502596112, 2015.

Li, Y., Lau, A. K. H., Fung, J. C. H., Zheng, J. Y., and Liu, S. C.: Importance of NOx control for peak ozone reduction in the Pearl River Delta region, J. Geophys. Res.-Atmos., 118, 9428-9443, doi:10.1002/jgrd.50659, 2013.

Liu, Y., Shao, M., Lu, S. H., Chang, C. C., Wang, J. L., and Fu, L. L.: Source apportionment of ambient volatile organic compounds in the Pearl River Delta, China: Part II, Atmos. Environ., 42, 6261-6274, doi:10.1016/j.atmosenv.2008.02.027, 2008.

Liu, Y., Yuan, B., Li, X., Shao, M., Lu, S., Li, Y., Chang, C. C., Wang, Z., Hu, W., Huang, X., He, L., Zeng, L., Hu, M., and Zhu, T.: Impact of pollution controls in Beijing on atmospheric oxygenated volatile organic compounds (OVOCs) during the 2008 Olympic Games: observation and modeling implications, Atmos. Chem. Phys., 15, 3045-3062, doi:10.5194/acp-15-3045-2015, 2015.

Louie, P. K. K., Watson, J. G., Chow, J. C., Chen, A., Sin, D. W. M., and Lau, A. K. H.: Seasonal characteristics and regional transport of $PM_{2.5}$ in Hong Kong, Atmos. Environ., 39, 1695-1710, doi:10.1016/j.atmosenv.2004.11.017, 2005.

Nelson, P. F., and Quigley, S. M.: The Hydrocarbon Composition Of Exhaust Emitted From Gasoline Fueled Vehicles, Atmos. Environ., 18, 79-87, doi:10.1016/0004-6981(84)90230-0, 1984.

Ng, N. L., Herndon, S. C., Trimborn, A., Canagaratna, M. R., Croteau, P. L., Onasch, T. B., Sueper, D., Worsnop, D. R., Zhang, Q., Sun, Y. L., and Jayne, J. T.: An Aerosol Chemical Speciation Monitor (ACSM) for Routine Monitoring of the Composition and Mass Concentrations of Ambient Aerosol, Aerosol Sci. Tech., 45, 780-794, 2011.

Ogren, J. A., and Charlson, R. J.: Elemental Carbon in the Atmosphere-Cycle and Lifetime, Tellus B., 35, 241-254, 1983.

Parrish, D. D., and Zhu, T.: Clean Air for Megacities, Science, 326, 674-675,

doi:10.1126/science.1176064, 2009.

Qin, Y., Tonnesen, G. S., and Wang, Z.: Weekend/weekday differences of ozone, NOx, Co, VOCs, PM10 and the light scatter during ozone season in southern California, Atmos. Environ., 38, 3069-3087, doi:10.1016/j.atmosenv.2004.01.035, 2004.

Schafer, H., Myronova, N., and Boden, R.: Microbial degradation of dimethylsulphide and related C-1-sulphur compounds: organisms and pathways controlling fluxes of sulphur in the biosphere, J. Exp. Bot., 61, 315-334, doi:10.1093/jxb/erp355, 2010.

Schauer, J. J., Kleeman, M. J., Cass, G. R., and Simoneit, B. R. T.: Measurement of emissions from air pollution sources. 2. C-1 through C-30 organic compounds from medium duty diesel trucks, Environ. Sci. Technol., 33, 1578-1587, doi:10.1021/Es980081n, 1999.

Schneider, J., Hock, N., Weimer, S., and Borrmann, S.: Nucleation particles in diesel exhaust: Composition inferred from in situ mass spectrometric analysis, Environ. Sci. Technol., 39, 6153-6161, doi:10.1021/es049427m, 2005.

Shi, G. L., Liu, G. R., Tian, Y. Z., Zhou, X. Y., Peng, X., and Feng, Y. C.: Chemical characteristic and toxicity assessment of particle associated PAHs for the short-term anthropogenic activity event: During the Chinese New Year's Festival in 2013, Sci. Total Environ., 482, 8-14, doi:10.1016/j.scitotenv.2014.02.107, 2014.

Singh, H., Chen, Y., Staudt, A., Jacob, D., Blake, D., Heikes, B., and Snow, J.: Evidence from the Pacific troposphere for large global sources of oxygenated organic compounds, Nature, 410, 1078-1081, doi:10.1038/35074067, 2001.

Stelson, A. W., and Seinfeld, J. H.: Relative-Humidity And Temperature-Dependence Of the Ammonium-Nitrate Dissociation-Constant, Atmos. Environ., 16, 983-992, doi:10.1016/0004-6981(82)90184-6, 1982.

Subramanian, R., Kok, G. L., Baumgardner, D., Clarke, A., Shinozuka, Y., Campos, T. L., Heizer, C. G., Stephens, B. B., de Foy, B., Voss, P. B., and Zaveri, R. A.: Black carbon over Mexico: the effect of atmospheric transport on mixing state, mass absorption cross-section, and BC/CO ratios, Atmos. Chem. Phys., 10, 219-237, doi:10.5194/acp-10-219-2010, 2010.

Sun, Y. L., Wang, Z. F., Fu, P. Q., Yang, T., Jiang, Q., Dong, H. B., Li, J., and Jia, J. J.: Aerosol composition, sources and processes during wintertime in Beijing, China, Atmos. Chem. Phys.,13, 4577–4592, doi:10.5194/acp-13-4577-2013, 2013.

Sun, Y. L., Wang, Z. F., Du, W., Zhang, Q., Wang, Q. Q., Fu, P. Q., Pan, X. L., Li, J., Jayne, J., and Worsnop, D. R.: Long-term real-time measurements of aerosol particle composition in Beijing, China: seasonal variations, meteorological effects, and source analysis, Atmos. Chem. Phys., 15, 10149-10165, doi:10.5194/acp-15-10149-2015, 2015.

Sun, Y. L., Wang, Z., Wild, O., Xu, W., Chen, C., Fu, P., Du, W., Zhou, L., Zhang, Q., Han, T., Wang, Q., Pan, X., Zheng, H., Li, J., Guo, X., Liu, J., and Worsnop, D. R.: "APEC Blue": Secondary Aerosol Reductions from Emission Controls in Beijing, Sci. Rep., 6, 20668, doi:10.1038/srep20668, 2016.

Tan, P. H., Chou, C., Liang, J. Y., Chou, C. C. K., and Shiu, C. J.: Air pollution "holiday effect" resulting from the Chinese New Year, Atmos. Environ., 43, 2114-2124, doi:10.1016/j.atmosenv.2009.01.037, 2009.

Wang, S.; Chai, F.; Xia, G.; Zhang, H.; Zhang, M.; Xue, Z.; Source Apportionment and Characteristics of SO2 in Shenzhen City. Res. Environ. Sci., 10 (22), 1128–1133, 2009 (in Chinese).

Wang, T., Nie, W., Gao, J., Xue, L. K., Gao, X. M., Wang, X. F., Qiu, J., Poon, C. N., Meinardi, S., Blake, D., Wang, S. L., Ding, A. J., Chai, F. H., Zhang, Q. Z., and Wang, W. X.: Air quality during the 2008 Beijing Olympics: secondary pollutants and regional impact, Atmos. Chem. Phys., 10, 7603-7615, doi:10.5194/acp-10-7603-2010, 2010.

Wang, X. M., Sheng, G. Y., Fu, J. M., Chan, C. Y., Lee, S. G., Chan, L. Y., and Wang, Z. S.: Urban roadside aromatic hydrocarbons in three cities of the Pearl River Delta, People's Republic of China, Atmos. Environ., 36, 5141-5148, doi:10.1016/S1352-2310(02)00640-4, 2002.

Xu, H. M., Tao, J., Ho, S. S. H., Ho, K. F., Cao, J. J., Li, N., Chow, J. C., Wang, G. H., Han, Y. M., Zhang, R. J., Watson, J. G., and Zhang, J. Q.: Characteristics of fine particulate non-polar organic compounds in Guangzhou during the 16th Asian Games: Effectiveness of air pollution controls, Atmos. Environ., 76, 94-101, doi:10.1016/j.atmosenv.2012.12.037, 2013.

Zhang, L., Shao, J. Y., Lu, X., Zhao, Y. H., Hu, Y. Y., Henze, D. K., Liao, H., Gong, S. L., and Zhang, Q.: Sources and Processes Affecting Fine Particulate Matter Pollution over North China: An Adjoint Analysis of the Beijing APEC Period, Environ. Sci. Technol., 50, 8731-8740, doi:10.1021/acs.est.6b03010, 2016.

Zhang, Q., Worsnop, D. R., Canagaratna, M. R., and Jimenez, J. L.: Hydrocarbon-like and oxygenated organic aerosols in Pittsburgh: insights into sources and processes of organic aerosols, Atmos. Chem.

Phys., 5, 3289-3311, 2005.

Zhang, Q., Jimenez, J. L., Worsnop, D. R., and Canagaratna, M.: A case study of urban particle acidity and its influence on secondary organic aerosol, Environ. Sci. Technol., 41, 3213-3219, doi:10.1021/es061812j, 2007.

Zhang, Y. H., Hu, M., Zhong, L. J., Wiedensohler, A., Liu, S. C., Andreae, M. O., Wang, W., and Fan, S. J.: Regional Integrated Experiments on Air Quality over Pearl River Delta 2004 (PRIDE-PRD2004): Overview, Atmos. Environ., 42, 6157-6173, doi:10.1016/j.atmosenv.2008.03.025, 2008.

Zhao, J., Du, W. J., Zhang, Y. J., Wang, Q. Q., Chen, C., Xu, W. Q., Han, T. T., Wang, Y. Y., Fu, P. Q., Wang, Z. F., Li, Z. S., and Sun, Y. L.: Insights into aerosol chemistry during the 2015 China victory day parade: results from simultaneous measurements at ground level and 260 m in Beijing, Atmos. Chem. Phys., 17, 1-29, doi:10.5194/acp-17-3215-2017, 2016.

Zheng, J. Y., Shao, M., Che, W. W., Zhang, L. J., Zhong, L. J., Zhang, Y. H., and Streets, D.: Speciated VOC Emission Inventory and Spatial Patterns of Ozone Formation Potential in the Pearl River Delta, China, Environ. Sci. Technol., 43, 8580-8586, doi:10.1021/es901688e, 2009.