Influence of road traffic emissions upon air quality. Comparison between Beijing and a European city

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Introduction

Beijing air quality suffers from frequently occurring air pollution events. Road traffic seems to be a main source of air pollutants.

In Europe several emission reduction measures for road traffic are performed and EURO 6 will be implemented during the next 3 years for all vehicles.

The objective of this study is to compare road traffic emissions in Beijing, China, and Augsburg, Germany. The investigated compounds are NO, NO_2 and HCHO, which are influenced by road emissions, as well as O_3, a secondary air pollutant. NO and NO_2 are of interest for secondary aerosol formation also. NO, NO_2, HCHO and O_3 are influenced by chemical and photochemical processes in the lower atmosphere too (Hao and Wang, 2005; Chan and Yao, 2008; Tang et al., 2009; Li et al., 2010; Zhou et al., 2010; Sun et al., 2011).

Within this study Differential Optical Absorption Spectroscopy (DOAS) has been used as measurement device. In comparison to in situ measurements the advantage is on path-integrated concentrations of air pollutants and it allows paths across roads or motorways where in situ instrumentation can never be installed (see also Schäfer et al., 2005).

Methodology

A DOAS system was operated for two years in Beijing and half a year in Augsburg together with in situ instrumentation to study the diurnal variation of gaseous pollutants.

Information about several emission sources can be provided by path-integrated air pollution measurements at different directions (Schäfer et al., 2008). The DOAS system from OPSIS GmbH contains an emitter/receiver unit pointing to three retro-reflectors. In Beijing one path was measured with a retro-reflector at a lamp mast across a small street and a motorway (Badaling Motorway; 568 m path length) 10 m above street level. Another path (126 m length) was in the same direction but only across the small street. The third path (266 m length) was in the opposite direction of the motorway and of path 3 / path 1 across a park (urban background, see Figure 1). The emitter/receiver unit was located in a distance of 20 m to an in situ air pollution monitoring station at the roof of the SCAS building. A similar installation was realized in Augsburg across an intersection: the emitter/receiver unit was installed at the roof of a measurement van and the paths were across two traffic roads with two lanes for each direction in about 4.5 up to 10 m height above street level using lamp masts. Path 1 (150 m length) was across Friedberger Str. which consists of an additional lane for traffic to the Invernessalle, path 2 (222 m length) across a two-lane one-way road from Friedberger Str. to the Invernessallee and path 3 (196 m length) across that road and Invernessallee. In situ instruments were operated in a van in 20 m distance to the DOAS van and 10 m distance to the road traffic (see Figure 2).

The reliability of the different measurement methods was checked by calibration procedures and comparisons with in situ instrumentation during smooth weather conditions. To ensure the reliability of the data, reference calibration and multi-point calibration are necessary for the system. According to the experiences in the campaign, a calibration every half year is performed for inorganic gases as well as a calibration every three months for organic gases to ensure that instrument changes do not influence the data quality. An individual calibration system was used for the DOAS system calibration, including a calibration lamp, a calibration bench, and three calibration cells with different lengths. Concentrations of standard gases were

as listed below: NO_2 – 966 ppmv, NO – 1510 ppmv and O_3 – 1000 ppmv (generated by an O_3 generator). Only one reference calibration was taken for HCHO due to restricted gas supply. Different equivalent concentrations were realized by changing the length of calibration cells. The resulting linear regression of this multi-point calibration provided deviations lower than 9 % and squares of the correlation coefficient better than 0.995.

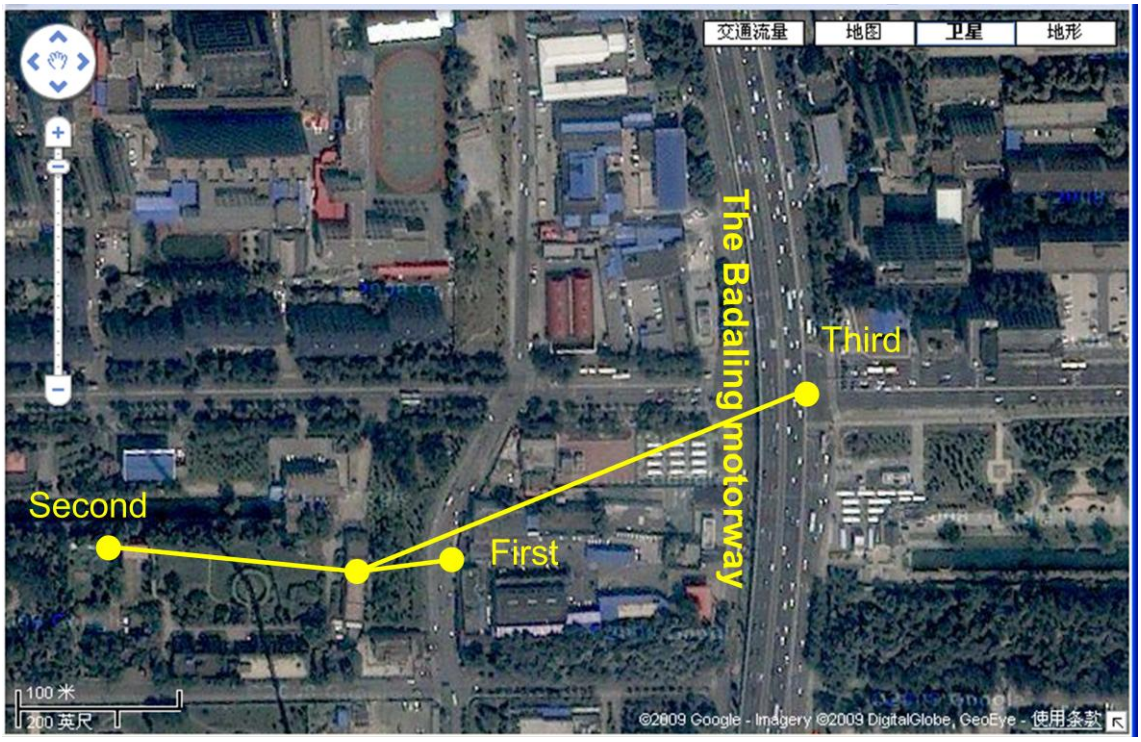

Figure 1: Measurement location in Beijing from April until July 2009: building of SCAS and 325 m meteorological tower together with DOAS light paths.

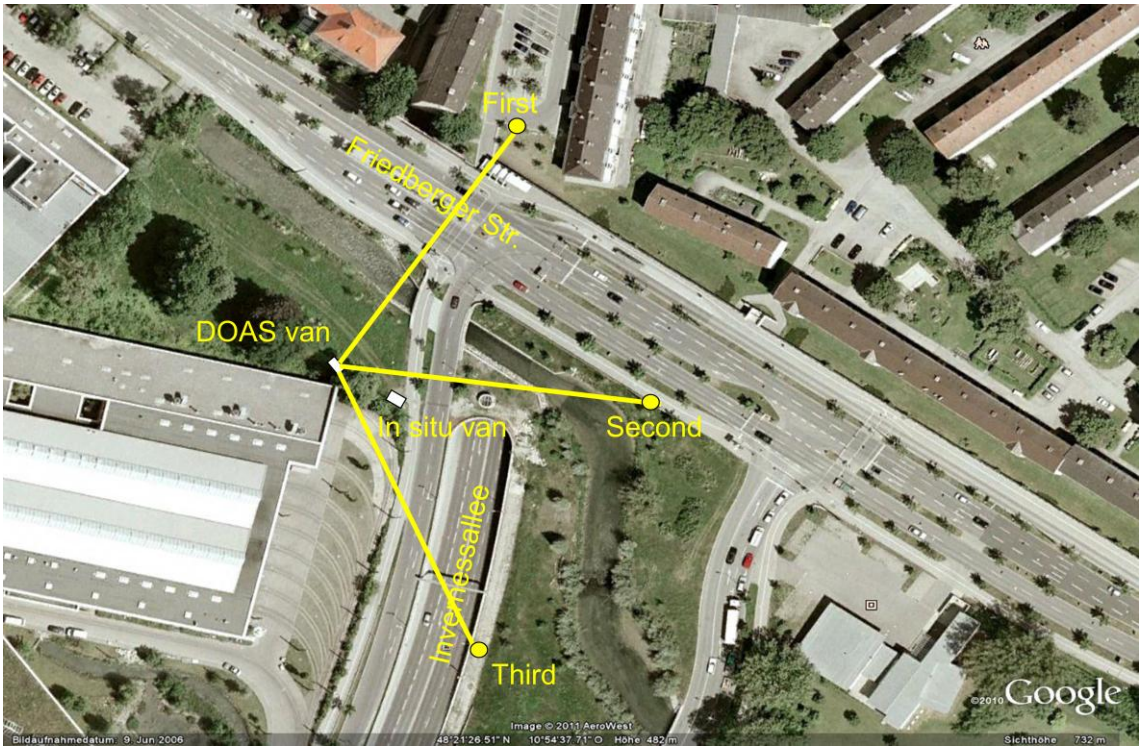

Figure 2: Measurement location in Augsburg from March until September 2012: two measurement vans at the intersection Friedberger Str. / Invernessallee together with DOAS light paths.

The in situ air pollution monitoring station in Beijing, which was used for comparison reasons, is equipped with a chemiluminescence NO-NO_2-NO_x analyzer (TE42i, Thermofisher, USA) and a UV photometric O_3 analyzer (49i, Thermofisher, USA). HCHO was compared from Oct 1st to Oct 18th, 2009 with a second DOAS system built up by the Anhui Institute of Optics and Fine Mechanics (AGS), CAS. The light path of this DOAS system was nearly parallel to path 3 from a building nearby the motorway to the meteorological tower in the park 60 m away from the SCAS building.

In Augsburg the following in situ instruments were operated for comparison reasons: a chemiluminescence NO-NO_2-NO_x analyzer (TE42C TL, Thermofisher, USA) and a UV absorption O_3 analyzer (APOA 350E, HORIBA Ldt., Japan).

One hourly mean values (based on a 1 minute temporal resolution of each compound for the DOAS system during 20 minutes measurement at each path) are determined from these measurements.

Results

Reliability of measurements

During the measurements in Beijing the DOAS concentration results of NO and NO_2 on path 2 (in the park) were higher than the in situ concentrations by a factor of 1.2 and 1.4, respectively (data are not shown here). This difference is caused by the better ventilation of the building roof than the park area. The O_3 DOAS result is lower than of the in situ instruments by a factor 0.97. The comparisons of the observation results between DOAS and in situ instruments for all these gases show strong linear correlations: 0.91, 0.86 and 0.97 respectively. The factor for HCHO concentrations between OPSIS DOAS path 3 and AGS DOAS is 0.9 and the linear correlation coefficient R^2 is 0.70. The difference between the two systems is mainly caused by the small deviation of the location of the two light paths.

In Augsburg the in situ instruments were located close to the road traffic. In this case the data are limited comparable with the path measurements of the DOAS system.

Air pollutant concentration in Beijing and Augsburg

Diurnal variations according to the observation of the DOAS system and in situ instruments are very similar. This is the case for path 3 across the motorway for NO_2, O_3 and HCHO and path 1 for NO in Beijing (this path is investigated because here is the optimum path length for this compound) as well as path 1 across the Friedberger Str. in Augsburg. In Figures 3 – 6 the error bars denote for the standard error of the concentrations for hourly means. Especially for NO and O_3 the temporal variation of the graphs seems to be identical.

NO shows highest concentrations during morning traffic peak hours (Figure 3: 6:00). The lowest value is at the afternoon till 18:00 and the NO concentration increases again up to a small peak value at about 21:00. After that period the night-time minimum level in Beijing is higher than in the afternoon due to a more stable atmosphere during evening and night hours. In Augsburg the concentrations of the DOAS system are a little bit higher than of the in situ instruments. This difference is much higher in Beijing. In Augsburg the DOAS measurements are closer to the road traffic emission sources than the in situ measurements. In Beijing it is caused by the distance of the in situ instruments to the street of about 50 m whereas the DOAS path is across the street.

As presented in Figure 4 the main peak of NO_2 concentration appears in the morning hours (in Beijing its duration is much longer than in Augsburg) but the evening peak at 21:00 has about the same amount (in Beijing it is even a little bit higher). Due to the high proportion of NO within the emitted NO_x, titration of O_3 becomes a very important source for NO_2. This leads to high NO_2 peak concentrations in the morning and in the evening and higher ozone concentrations in the evening than in the morning (see Figure 5). The minimum is at about 15:00 which is caused by convection mainly. The afternoon minimum is in Beijing much lower than the night-time concentrations which are influenced by high stability of the atmosphere. In Beijing the concentrations and temporal variations of the in situ measurements are much smaller than detected by the DOAS system as it is the case for the NO concentrations also. In Augsburg it is the opposite – the in situ concentrations of NO_2 are a little bit higher than the DOAS

concentrations because of the titration effect of O_3 (see Figure 5) at the in situ measurement site.

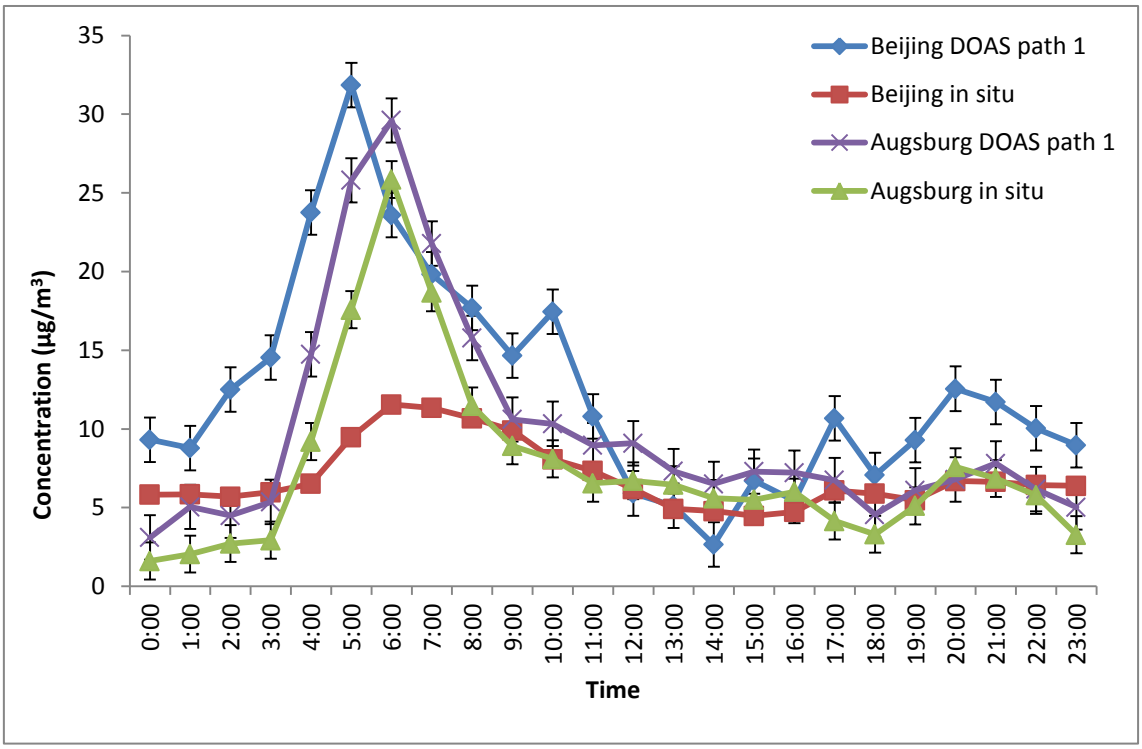

Figure 3: Mean diurnal variations of NO in Beijing in July 2009 and in Augsburg in July 2012.

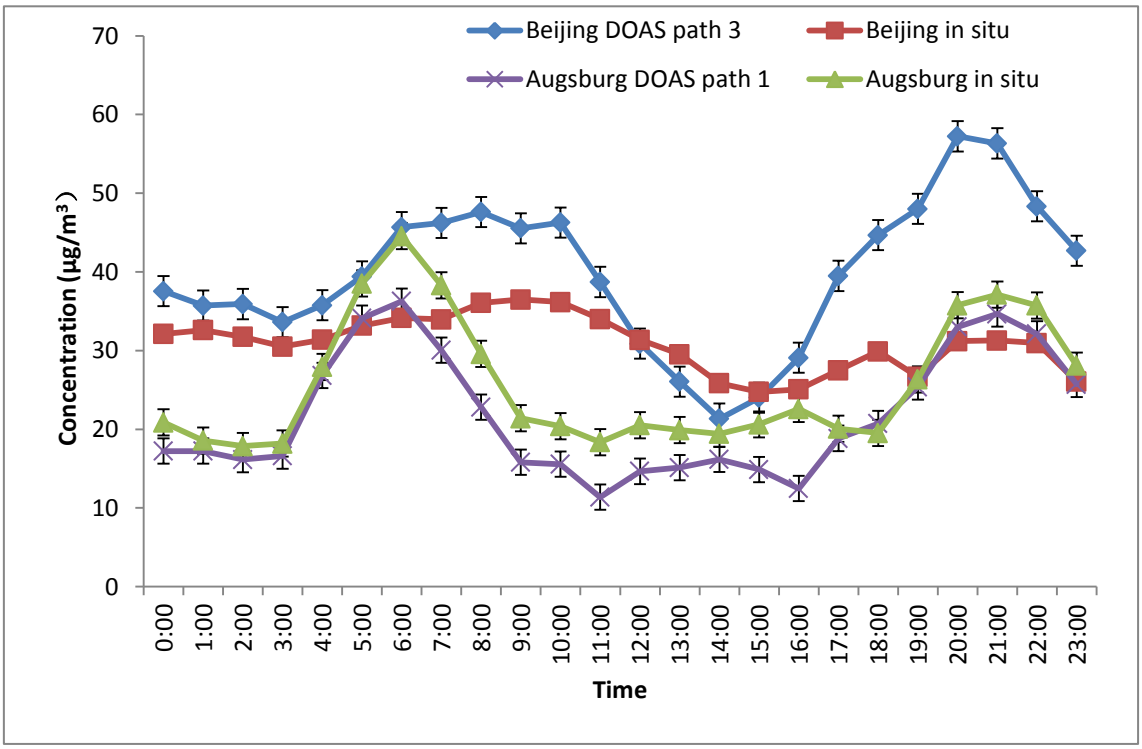

Figure 4: Mean diurnal variations of NO_2 in Beijing in July 2009 and in Augsburg in July 2012.

The O_3 daily variation presents one peak at about 15:00 due to the photochemical production (Figure 5). The lowest value of O_3 concentration appears at about 6:00, just at the time of the NO morning peak, and the O_3 peak is in line with the minimum of NO in the afternoon. In Beijing

the in situ O_3 concentrations are a little bit higher than the DOAS concentrations because of the less availability of NO for titration of O_3 at the in situ measurement site than at the DOAS path. This effect is more pronounced in Augsburg.

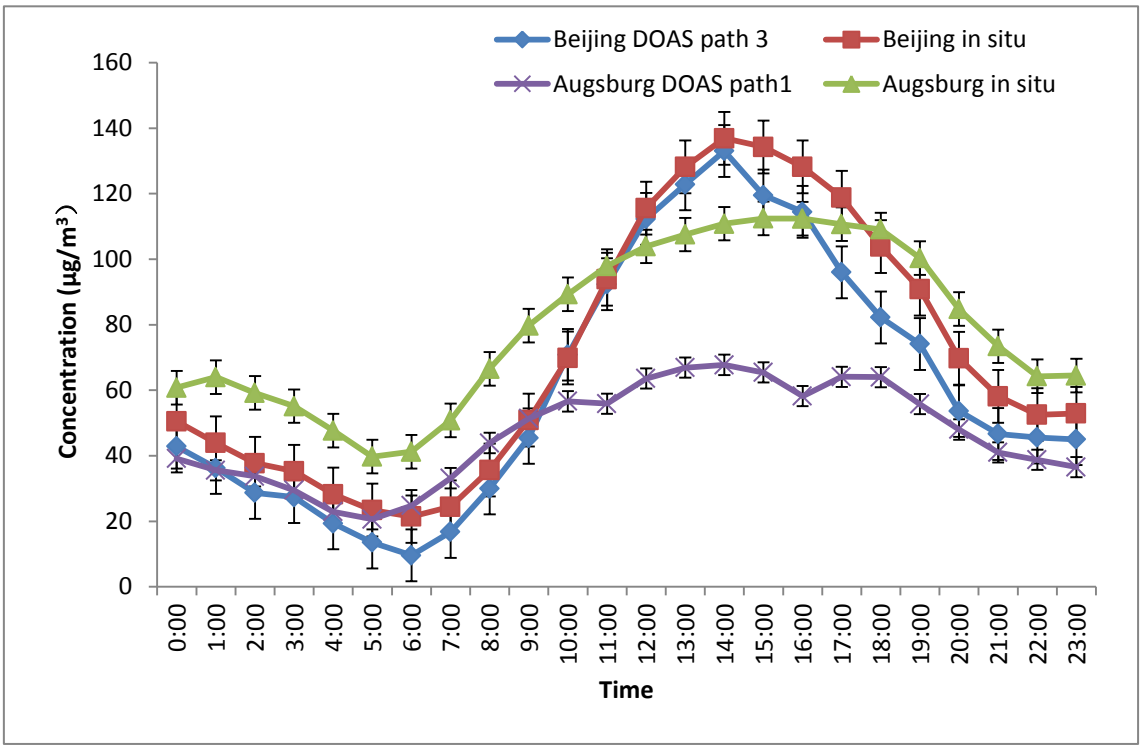

Figure 5: Mean diurnal variations of O_3 in Beijing in July 2009 and in Augsburg in July 2012.

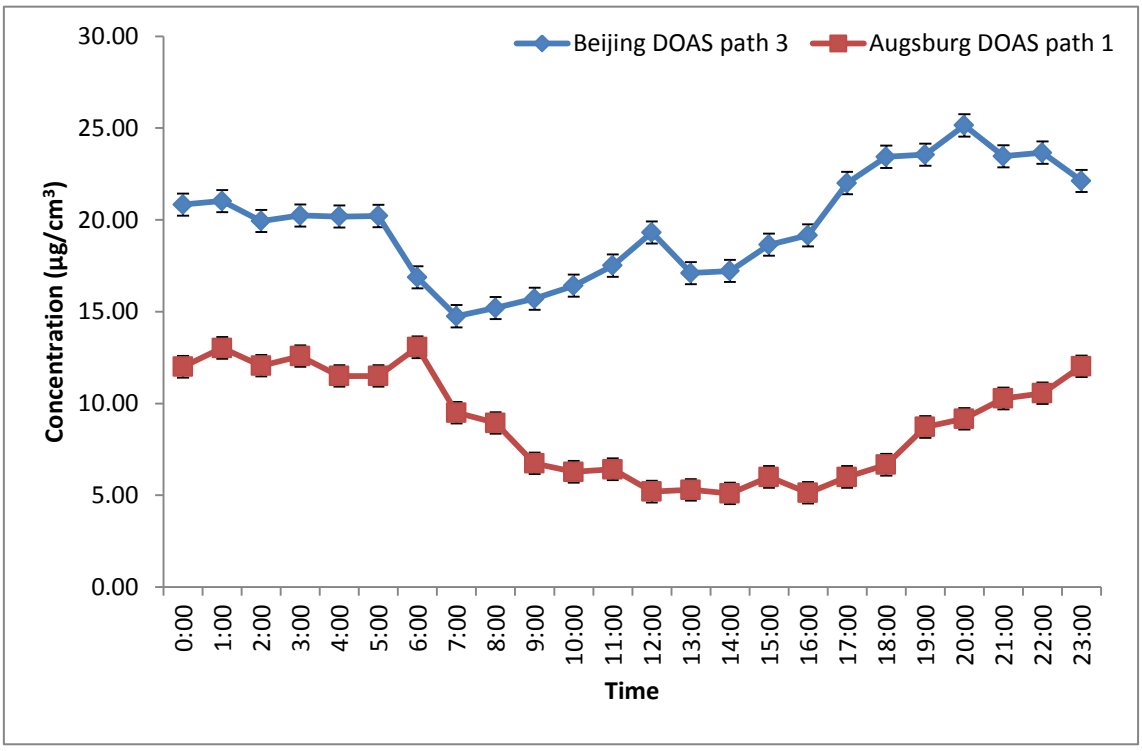

Figure 6: Mean diurnal variations of HCHO in Beijing in July 2009 and in Augsburg in April 2012.

Daily variations of HCHO concentration are provided here by the DOAS systems only (Figure 6). The diurnal variation of HCHO concentration has only one peak. In Beijing the

concentrations increased to a maximum value at about 20:00 with more or less the same level until the morning hours. The minimum level was reached between 8:00 and 15:00. In Augsburg the variations are in the same order but without a pronounced maximum late in the evening. The decrease in the morning hours until the minimum level lasts from 12:00 until 17:00.

Discussion and conclusions

Major air pollutants in Beijing were significantly decreased during the past, such as SO_2, which is mainly originated by coal burning (Chan and Yao, 2008). However, with the changes of energy production technologies and the increasing amount of vehicles the air pollution is characterized and modified by vehicle exhausts (NO and NO_2), O_3 and fine particulates (Hao and Wang, 2005; Tang et al., 2009). According to the China Statistical Yearbook 2010 the total number of civil vehicles in Beijing increased up to 3.68 million until the end of 2009. These are 3.45 million passenger cars, 0.18 million lorries and 0.04 million of other vehicle types.

In August 2008 the Olympics Games were hosted in Beijing. To improve the air quality before and during the Olympic Games a series of policies were carried out to reduce the emissions of air pollutants. One of the most important measures was the control of the amount of vehicles on the roads which was reduced by nearly half. Nevertheless the total number of vehicles is increasing further since the Olympic Games. Compared to our observations the NO_x concentrations (Figures 3, 4) were lower and the O_3 concentrations (Figure 5) were higher during the Olympic Games (Sun et al., 2011).

The results presented here show obvious differences between the in situ instruments and the DOAS system for all compounds. The differences between the two measurement platforms are influenced by local emissions, mainly road traffic emissions and chemical transformations.

Similarities and differences of the HCHO results in Beijing exist in comparison to other research work. Here, the concentration range of HCHO from continuous DOAS observations in July 2009 is between 15 and 25 µg/m^3. Pang and Mu (2006) report HCHO concentrations in Beijing at some days in 2005 and 2006. Ambient air was sampled by 2,4-dinitrophenylhydrazine(2,4-DNPH) and analyzed by high-pressure liquid chromatography (HPLC) in one hour intervals of certain days from 8:00 to 20:00. The concentration ranged between 1 ppbv (1 µg/m^3) and 34 ppbv (42 µg/m^3) and 6 ppbv (7 µg/m^3) and 30 ppbv (37 µg/m^3) in both years. In 2008 Li et al. (2010) used a fluorometric instrument for HCHO monitoring and found a concentration range from 2 ppbv (2 µg/m^3) up to 20 ppbv (25 µg/m^3) i.e. similar to those provided here.

The comparison between air pollution characteristics in Beijing and Augsburg measured by DOAS across road traffic shows the following characteristics. The concentrations of NO_2 and of O_3 are about 40 % and of HCHO about 100 % higher in Beijing than in Augsburg. The NO concentrations are nearly similar. The diurnal variations of all compounds in Beijing and Augsburg are nearly identical. This is in coincidence with similar temporal variation of road traffic pattern in both cities which is the main source of NO and NO_2 in these urban areas. The daily HCHO concentration variation seems to be caused by the stability of the lower atmosphere mainly as the emission sources (road traffic, biomass burning, vegetation) are wide spread: high stability during the night enhances concentrations and convection during the day reduces concentrations.

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