CONTENTS

Aquatic environment
Effects of physical and chemical characteristics of surface sediments in the formation of shallow lake algae-induced black bloom
Qiushi Shen, Cheng Liu, Qinlin Zhou, Jingge Shang, Lei Zhang, Chengxin Fan ................................................................. 2353
A fishy odor episode in a north China reservoir: Occurrence, origin, and possible odor causing compounds
Yunyun Zhao, Jianwei Yu, Bing Su, Wei An, Min Yang ................................................................. 2361
Advanced lignin-acrylamide water treatment agent by pulp and paper industrial sludge: Synthesis, properties and application (Cover story)
Hongyan Rong, Baoyu Gao, Yanxia Zhao, Shenglei Sun, Zhongliang Yang, Yan Wang, Qinyan Yue, Qian Li ................................................................. 2367
Effect of dissolved organic matter on sorption and desorption of phenanthrene onto black carbon
Jinghuang Zhang, Mengchang He ................................................................. 2378
Biosorption of clofibric acid and carbamazepine in aqueous solution by agricultural waste rice straw
Zhanguang Liu, Xuefei Zhou, Xiaohua Chen, Chaomeng Dai, Juan Zhang, Yafei Zhang ................................................................. 2384
Effects of idle time on biological phosphorus removal by sequencing batch reactors
Dawen Gao, Hang Yin, Lin Liu, Xing Li, Hong Liang ................................................................. 2396
Oxidation behavior of ammonium in a 3-dimensional biotfilm-electrode reactor
Jinqing Tang, Jingsong Guo, Fang Fang, Youpeng Chen, Lijing Li, Lin Yang ................................................................. 2403
Isolation of a salt tolerant laccase secreting strain of Trichoderma sp. NFCCI-2745 and optimization of culture conditions and assessing its effectiveness in treating saline phenolic effluents
L. M. Divya, G. K. Prasanth, C. Sadasivan ................................................................. 2410
Effect of operating parameters on sulfide biotransformation to sulfur
Weiguo Liu, Cunzhou Liang, Jiaping Chen, Chong Zhu ................................................................. 2417
Iron and lead ion adsorption by microbial flocculants in synthetic wastewater and their related carbonate formation
Minjie Yao, Bin Lian, Haishu Dong, Jiongchao Hao, Congqiang Liu ................................................................. 2422

Atmospheric environment
Estimation of carbon dioxide flux and source partitioning over Beijing, China
Tao Song, Yueyi Wang, Yang Sun ................................................................. 2429

Terrestrial environment
Changes in heavy metal contents in animal feeds and manures in an intensive animal production region of China
Hui Wang, Yuanhua Dong, Yunya Yang, Gurpal S. Toor, Xumei Zhang ................................................................. 2435
Polybrominated diphenyl ethers in soil from three typical industrial areas in Beijing, China
Yongfei Zhang, Shan Fu, Xinchun Liu, Zheng Li, Yuan Dong ................................................................. 2443
Water extraction kinetics of metals, arsenic and dissolved organic carbon from industrial contaminated poplar leaves
Muhammad Shahid, Tianian Xiong, Maryse Castre-Rouelle, Tibo Leveque, Camille Dumat ................................................................. 2451

Environmental catalysis and materials
Photocatalytic activity of TiO$_2$ containing anatase nanoparticles and rutile nanoflower structure consisting of nanorods
Zhishao He, Qiaolan Cai, Huying Fang, Guohua Sui, Jianping Qu, Shuang Song, Jianmeng Chen ................................................................. 2460
Fe$_3$O$_4$ particles as superior catalysts for low temperature selective catalytic reduction of NO with NH$_3$
Xiaobo Wang, Kejie Gui ................................................................. 2469
Mercury removal using ground and calcined mussel shell
Susana Peña-Rodríguez, Alispso Bermúdez-Cosso, Juan Carlos Núñez-Muñoz, Manuel Arias-Estévez, María J. Fernández-Sanjurjo, Esperanza Álvarez-Rodríguez, Avelino Núñez-Delgado ................................................................. 2476
Enhanced photocatalytic activity of quantum-dot-sensitized one-dimensionally-ordered ZnO nanorod photocatalyst
Jinzhou Huang, Song Liu, Lei Kuang, Yongdan Zhao, Tao Jiang, Shiyou Liu, Xinjun Xu ................................................................. 2487
Effect of chromium oxide as active site over TiO$_2$-PILC for selective catalytic oxidation of NO
Jinxing Zhang, Shule Zhang, Wei Cai, Qin Zhong ................................................................. 2492
Catalytic evaluation of promoted CeO$_2$-ZrO$_2$ by transition, alkali, and alkaline-earth metal oxides for diesel soot oxidation
Ali Almehbachamarkerti, Abas Ali Khodadadi, Yadollah Mortazavi, Ahmad Nemati ................................................................. 2498
Effects of amine, amine salt and amide on the behaviour of carbon dioxide absorption into calcium hydroxide suspension to precipitate calcium carbonate
Wittaya Chuauij, Mitsuru Nakano, Kazumasa Takatori, Toshiya Kojima, Yoshiaki Wakimoto, Yoshiaki Fukushima ................................................................. 2507
Serial parameter: CN 11-2629/X*1989*m*163*en*P*21*2013-12
Estimation of carbon dioxide flux and source partitioning over Beijing, China

Tao Song, Yuesi Wang, Yang Sun*

State key laboratory of Atmospheric Boundary Layer Physics and Atmospheric Chemistry, Institute of Atmospheric Physics Chinese Academy of Sciences, Beijing 100029, China. E-mail: suny@dq.cern.ac.cn

Received 26 February 2013; revised 29 August 2013; accepted 06 September 2013

Abstract

The magnitude and partitioning of carbon dioxide emission from the urban area in Beijing, China was estimated based on a statistical approach. Results showed that the urban surface is a net source of CO₂ to atmosphere. The main sources of CO₂ are vehicles, which accounted for 75.5% and 38.9% of CO₂ emission in summer and winter, respectively. At midday in summer, the CO₂ uptake of −0.034 mg/(m²·sec) indicated that vegetation is an important sink of CO₂ in summer. Comparison between the annual emission rates of CO₂ from the statistical approach and that directly measured by the eddy covariance technique implies that a bottom-up emission approach is a viable means to estimate CO₂ emission in an urban area.

Key words: CO₂ emission; source; eddy covariance

DOI: 10.1016/S1001-0742(12)60336-2

Introduction

Although cities take up only about 2% of global land area, they release more than 70% of the total emissions of carbon dioxide (CO₂) of anthropogenic origin (Canadell et al., 2009). In cities, CO₂ is emitted by the burning of fossil fuel associated with transport, energy use in households and public buildings, as well as manufacturing and industry (Velasco and Roth, 2010). As the often dominant and fastest growing sector, the transport sector directly releases CO₂ by burning gasoline or diesel fuel. CO₂ emissions from households, public buildings and industry have a direct local contribution from combustion processes (e.g. use of natural gas or biomass for cooking and heating). The urban CO₂ fluxes are also influenced by natural sources and sinks. Urban surfaces covered by vegetation take up CO₂ from the atmosphere during daytime and release it through respiration at night.

Accurate estimates of the magnitude and partitioning of CO₂ emissions are needed to understand how urban emissions affect the regional carbon exchange and explore how these impacts may change with urban growth and development patterns. A number of methods are used to estimate the CO₂ exchange from cities. As a direct flux measurement, eddy covariance (EC) has been employed to investigate urban CO₂ emissions in Europe (Nemitz et al., 2002; Soegaard and Møller-Jensen, 2003; Vogt et al., 2003; Grimmond et al., 2004; Matese et al., 2009; Pawlak et al., 2011; Helfter et al., 2011), North America (Grimmond et al., 2002; Bergeron and Strachan, 2011) and Asia (Moriwaki and Kanda, 2004; Song and Wang, 2012). However, the aforementioned EC method could not give information on the partitioning of CO₂ emissions, in other words, the EC method could not be used to validate solely building energy models or transportation models as it quantifies the total CO₂ emitted from an urban area without identifying the specific sources and sinks (Christen et al., 2011). The contribution of various sources to total CO₂ emissions could be quantified by a statistical method that accounts for emission factors and fossil fuel consumption data. Using a statistical method, Moriwaki and Kanda (2004) estimated the individual release of CO₂ from traffic, human activities, industrial activities, district heating, human exhalation and vegetation in Tokyo, Japan. Combined with the dynamic inventorial data of road traffic and gas consumption, Gioli et al. (2012) estimated CO₂ and CH₄ daily flux and source partitioning in an urban area of Florence, Italy. A combination of top-down inventory and bottom-up modeling of individual objects (buildings, vegetation and traffic counts) was applied by Christen et al. (2011), who estimated local CO₂ emissions at 50 m grid resolution for an urban area in Vancouver, Canada. The results from both Gioli et al. (2012) and Christen et al. (2011) showed that CO₂ emissions estimated by inventorial data were in agreement with that directly measured...
by the EC method on an annual and monthly scale, which suggested the validity of the indirect inventorial approach on estimation of CO\textsubscript{2} emissions and source partitioning in urban areas. However, it was still a challenge to obtain the fine-scale dynamic inventorial data related to CO\textsubscript{2} emission due to privacy and logistical reasons.

The purpose of this study is to investigate the magnitude and partitioning of CO\textsubscript{2} emissions from the urban area in Beijing by a simple inventory method based on published yearbook statistics that were usually open to access. The method was evaluated by comparison of annual emissions estimated using the statistical method to that obtained from EC method. The validity of the developed method may be helpful in assessing the CO\textsubscript{2} emission from cities where the dynamic inventorial data are not available or difficult to access.

1 Materials and methods

1.1 Source of CO\textsubscript{2}

Following the statistical methods used to estimate the emissions of CO\textsubscript{2} from urban area proposed by Moriwaki and Kanda (2004), we roughly estimated individual CO\textsubscript{2} fluxes from vehicles, human activities, industrial activities, district heating, human exhalation and vegetation in Beijing.

The vehicular emissions were estimated using two methods. Method 1 was the same as that described by Moriwaki and Kanda (2004) and used the following values: a total vehicle number of 3.4 \times 10^6 (Beijing Transport Annual Report, 2010), a mean annual mileage of 2.31 \times 10^4 km/(vehicle-yr) (Beijing Transport Annual Report, 2006), and a daily mean traffic in the Beijing metropolitan area (1368 km\textsuperscript{2}) of about 1.13 \times 10\textsuperscript{5} vehicle kilometers/hr. Assuming a gas mileage of 8 km/L, total consumption of fuel was 1.22 \times 10^8 L/hr. CO\textsubscript{2} flux from traffic was estimated by dividing by the metropolitan area and multiplying by the emission coefficient of 2360 g/L. In Method 2, the total consumption of fuel was directly calculated using the total vehicle numbers of 3.4 \times 10^6 and the total monthly fuel consumption of 232 L/(vehicle-month) (Beijing Transport Annual Report, 2006). The total fuel consumption estimated by Method 2 (1.29 \times 10^8 L/hr), was 8.5% lower than that by Method 1. As in Method 1, CO\textsubscript{2} flux from traffic based on method 2 was estimated by dividing by the metropolitan area and multiplying by the emission coefficient of 2360 g/L.

The emissions from human activities were estimated using the following method. The consumption of fossil fuels was estimated using total seasonal consumption of coal, natural gas and liquefied petroleum gas (LPG) per person (Table 1) and the population density of 14,000 persons per square kilometer estimated by averaging the population density of eight metropolitan districts (Beijing Statistics Yearbook, 2010). Using thermal values of 20, 56, and 6.22 MJ/m\textsuperscript{3} for coal, natural gas and LPG, respectively (IPCC, 2006), we converted the unit of mass of fossil fuel into energy. The CO\textsubscript{2} flux was estimated using the information of energy consumption per square kilometer per season and CO\textsubscript{2} emission rates were 94.6, 63.1 and 56 g/MJ for coal, natural gas and LPG, respectively.

In the Beijing urban area, district heating in winter and industrial activities were both considerable sources of CO\textsubscript{2}. The CO\textsubscript{2} emissions from district heating were estimated using data on the consumption of fossil fuels (Table 2). We calculated the consumption of fossil fuels per square kilometer by dividing by the total area. The CO\textsubscript{2} fluxes were then estimated by multiplying fossil fuel consumption per square kilometer by the thermal values and the CO\textsubscript{2} emission rate. We assumed that the consumption of coal mainly represented CO\textsubscript{2} emissions from industrial activities. Using an annual coal consumption of 1.51 \times 10\textsuperscript{7} kg/yr (Tsinghua University, 2007) in the industrial sector of the Beijing metropolitan area, we calculated the annual consumption of coal per square kilometer. The CO\textsubscript{2} fluxes were then estimated by multiplying the annual consumption of coal by thermal values and the CO\textsubscript{2} emission rate.

The emissions from human exhalation were estimated using the method described by Moriwaki and Kanda (2004); they reported that the emission of CO\textsubscript{2} per person was 8.87 mg/sec. We calculated CO\textsubscript{2} flux by multiplying the human exhalation rate by the population density of 14,000 persons per square kilometer for metropolitan area.

The dominant forms of vegetation in this area were deciduous trees and lawns. We used reference flux data from an urban park located in the northeast Beijing metropolitan

---

Table 1: Energy consumption for household in different seasons (Song and Wang, 2012)

<table>
<thead>
<tr>
<th>Type of energy</th>
<th>Energy consumption*</th>
<th>Thermal values**</th>
<th>CO\textsubscript{2} emission factor (g/MJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>2.76 \times 10^8</td>
<td>20</td>
<td>95</td>
</tr>
<tr>
<td>LPG</td>
<td>1.73 \times 10^8</td>
<td>15</td>
<td>44</td>
</tr>
<tr>
<td>Fuel oil</td>
<td>1.87 \times 10^8</td>
<td>41</td>
<td>77</td>
</tr>
<tr>
<td>Natural gas</td>
<td>3.50 \times 10^8</td>
<td>36</td>
<td>56</td>
</tr>
<tr>
<td>Oil products</td>
<td>1.67 \times 10^8</td>
<td>41</td>
<td>73</td>
</tr>
<tr>
<td>Coking products</td>
<td>1.59 \times 10^8</td>
<td>28</td>
<td>97</td>
</tr>
</tbody>
</table>

* Units of kg/population for coal and LPG and MJ/population for natural gas. Original data obtained from Beijing statistical information net (www.bjstats.gov.cn//ldcxxt/tjfx/tjbj/200506/t20050602_27524.htm).

---

Table 2: Energy consumption for district heating in Beijing urban area

<table>
<thead>
<tr>
<th>Type of energy</th>
<th>Energy consumption*</th>
<th>Thermal values**</th>
<th>CO\textsubscript{2} emission factor (g/MJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>2.76 \times 10^8</td>
<td>20</td>
<td>95</td>
</tr>
<tr>
<td>LPG</td>
<td>1.73 \times 10^8</td>
<td>15</td>
<td>44</td>
</tr>
<tr>
<td>Fuel oil</td>
<td>1.87 \times 10^8</td>
<td>41</td>
<td>77</td>
</tr>
<tr>
<td>Natural gas</td>
<td>3.50 \times 10^8</td>
<td>36</td>
<td>56</td>
</tr>
<tr>
<td>Oil products</td>
<td>1.67 \times 10^8</td>
<td>41</td>
<td>73</td>
</tr>
<tr>
<td>Coking products</td>
<td>1.59 \times 10^8</td>
<td>28</td>
<td>97</td>
</tr>
</tbody>
</table>

* Data obtained from Tsinghua University, 2007; ** data obtained from Beijing statistical yearbook 2009; \textsuperscript{*} units of m\textsuperscript{3}/season for natural gas and LPG, kg/season for others; \textsuperscript{**} units of MJ/m\textsuperscript{3} for natural gas and LPG, MJ/kg for others.
area (Wang et al., 2011) and to estimate the fluxes from vegetation by multiplying by a green cover ratio of 30.9% (Hu, 2006). The CO$_2$ flux from bare soil was not included in this study.

### 1.2 Flux measurements by eddy covariance approach

The simple statistical approach mentioned above did not consider the heterogeneity and variability of the emission sources, which are the largest uncertainty sources. Direct EC measurements of CO$_2$ fluxes that include all anthropogenic and natural sources and sinks from a specific region can be used to evaluate emission inventories in a more precise way (Velasco and Roth, 2010).

Fluxes of CO$_2$ were measured continuously in Beijing, by EC during 2009, at a 140-m height on a 325 meteorological tower in a high-density residential area (39°58′E, 116°22′N). The EC set-up includes a sonic anemometer (Model CSAT3, Campbell Scientific Inc, Logan, Utah, USA) to measure the three wind speed components and sonic temperature, and an open-path infrared gas analyzer (Model LI-7500, LiCor Inc., Lincoln, Nebraska, USA), which measures H$_2$O and CO$_2$ concentration. The raw signals were collected at a rate of 10 Hz and stored on a datalogger (model CR5000, Campbell Scientific Inc., Logan, Utah, USA) for later post-processing. Additional details of the EC system were introduced by Song and Wang (2012). Finally, available data (after missing data due to downtime of instruments, sensor calibration and low-quality data) left approximately a 65% data coverage, equating to approximately 11387 measurement points in 2009. Similar to most long term EC measurements in urban area (Helfter et al., 2011; Pawlak et al., 2011), no gap-filling was attempted here due to the complex nature of the CO$_2$ exchange above urban surfaces.

### 1.3 Footprint

In contrast to a homogeneous surface where the fluxes from all parts of the surface are equal, in an inhomogeneous surface such as a city, the measured flux signal highly depended on the surface part having the strongest influence on the sensor and, therefore, the location and sizes of footprint (Velasco et al., 2005). The footprint analysis was performed using the analytical thermally stratified atmospheric surface layer model, which included sensor height, atmospheric stability and friction velocity as input parameters (Heish et al., 2000). This model was chosen because it provides a non-ecosystem-specific approach that is likely more applicable than others to an urban area (Matese et al., 2009). Figure 1 illustrates the source area responsible for 90% to 50% of the measured fluxes. In case of the source area responsible for 80% of the fluxes, the sector averaged footprint lengths generally ranged between 1 and 7 km with an average of 3 ± 1.1 km for unstable periods and between 13 and 38 km with an average of 27 ± 5.7 km for stable periods. According to the footprint analysis above, the CO$_2$ fluxes measured at 140 m height could respond to the signals of sources and sinks within several hundreds of square kilometers, which was a similar spatial scale to that of the whole Beijing urban area. Thus, the EC fluxes could be used to evaluate the CO$_2$ emissions from the urban area estimated based on the statistical approach.

### 2 Results and discussion

#### 2.1 Contributions of CO$_2$ fluxes from various sources

The daily vehicle CO$_2$ fluxes, averaged using two different statistical methods, were 0.45 and 0.56 mg/(m$^2$·sec). The CO$_2$ fluxes from vehicles had the same magnitude as the measured CO$_2$ fluxes, which, similar to previous studies, indicated that vehicles were a major contributor to CO$_2$ emissions in Beijing (Soegaard and Møller-Jensen, 2003; Moriwaki and Kanda, 2004; Velasco et al., 2005).

The CO$_2$ fluxes from human activities ranged seasonally from 0.07 in summer to 0.15 mg/(m$^2$·sec) in winter. Relative to Tokyo, the fluxes in Beijing were only about 10% as high in the winter. The lower household fluxes in winter could be attributed to the lower fuel consumption per household in Beijing. The household density in the urban area estimated based on the statistical approach was 5495 house per square kilometer (including 4049 registered households and 1446 unregistered households, calculated assuming the same proportion of registered households and permanent residents as unregistered households and temporary residents). The consumption was 308, 126 and 616 MJ house$^{-1}$ month$^{-1}$ for natural gas, LPG and coal respectively, which was estimated using statistical data on Beijing households (Beijing Statistical Yearbook 2009) and coal consumption for households in North China (Zhang, 2004). Although the household density (5495) was comparable to that in Tokyo (5011), the fuel consumption was significantly lower than the consumption of 1865 and 1340 MJ house$^{-1}$ month$^{-1}$ for gas and kerosene in Tokyo (Moriwaki and...
Kanda, 2004). Thus, there was less consumption of fossil fuels per square kilometer. Another reason the household CO$_2$ flux in Beijing was lower than that of Tokyo was that the energy consumption from house heating was not considered as a part of energy consumption from households in this study due to the operation of district heating in winter.

The CO$_2$ fluxes from house heating in winter were mainly determined by district heating. The house-heating flux of 0.56 mg/(m$^2$·sec) was similar to that from traffic, indicating that the district heating was a very important source of CO$_2$ in winter. That district heating is a prevailing source of CO$_2$ in winter has also been observed in other cities, Matese et al. (2009) reported that the CO$_2$ flux varied from 0.55 mg/(m$^2$·sec) (during the period when the domestic heating was off) up to 1.57 mg/(m$^2$·sec) (during the period when the domestic heating was operated) in Ferenze.

The CO$_2$ flux from human exhalations was 0.09 mg/(m$^2$·sec), which corresponded to 11.9% of the total flux in summer and 6.2% of that in winter. Due to comparable population densities (14,000 vs. 11,800 persons per square kilometer) this CO$_2$ flux was 18% higher than was estimated in Tokyo.

The average daily CO$_2$ fluxes from vegetation were – 0.034 mg/(m$^2$·sec) in summer and 0.32 mg/(m$^2$·sec) in winter. At midday in summer, the CO$_2$ uptake of –0.034 mg/(m$^2$·sec) was comparable with the total fluxes, which indicates that vegetation was an important sink of CO$_2$ in summer.

Summertime emissions of CO$_2$ from the urban area in Beijing were estimated to have been dominated by vehicles (75.5%), while human exhalation contributed 11.9% (Fig. 2). The contribution of vegetation (–4.6%) to total summer CO$_2$ emissions cannot be neglected, which offset approximate 90 ton/(km$^2$·month) emissions in summertime. Although vehicles were a significant contributor to total winter CO$_2$ emissions, the percentage of vehicle contribution was reduced to 38.9% due to the district heating in wintertime that accounted for approximately 38.3% of CO$_2$ emissions.

2.2 Direct flux measurement

Figure 3 shows monthly measured CO$_2$ fluxes in 2009. The seasonal average CO$_2$ fluxes was 127 g/(m$^2$·day) in winter when CO$_2$ emissions from district heating was expected to be highest and CO$_2$ uptake from vegetation was minimal, while it was 61 g/(m$^2$·day) in summer when CO$_2$ uptake from vegetation was highest and CO$_2$ emission from district heating was minimal. The CO$_2$ fluxes were 72 and 90 g/(m$^2$·day) in spring and autumn, respectively. These significant differences in CO$_2$ fluxes between seasons at our study site are consistent with previous observations at other urban sites (Soegaard and Møller-Jensen, 2003; Moriwaki and Kanda, 2004; Matese et al., 2009; Helfter et al., 2011) and are also consistent with data measured at a lower altitude of the same tower in 2008 (Song and Wang, 2012). For our site, the mean annual CO$_2$ flux of 32 kg/(m$^2$·yr) was considerably higher than those in most urban and suburban sites with the exception of the London urban center (35.5 kg/(m$^2$·yr)) (Helfter et al., 2011). The annual CO$_2$ emissions from urban areas of Copenhagen (Soegaard and Møller-Jensen, 2003), residential areas of Tokyo (Moriwaki and Kanda, 2004), residential areas of Melbourne (Coutts et al., 2007), the urban center area of Lodz (Pawlak et al., 2011), suburban areas of Montreal (Bergeron and Strachan., 2011), and residential areas of Vancouver (Christen et al., 2011) were 12.8, 11.1, 8.9, 10.8, 20.4 and 24.6 kg/(m$^2$·yr), respectively.

2.3 Comparisons of statistical approach with eddy covariance results

Due to the large uncertainties associated with the simple assumptions of the statistical approach, we did not expect the sum of the contributions would equal the measured EC results (Table 3). In summertime, the emission rate of 65.4 g/(m$^2$·day) obtained from the statistical approach is approximately 6% higher than that from EC, while in wintertime the emission rate of 124 g/(m$^2$·day) obtained from
Table 3 Comparison of measured and estimated CO$_2$ emissions on a monthly basis (unit: g/(m$^2$·day) for monthly mean value; g/(m$^2$·yr) for annual mean value).

<table>
<thead>
<tr>
<th></th>
<th>EC measured</th>
<th>Statistic approach</th>
<th>Difference</th>
<th>Vehicle</th>
<th>House-hold</th>
<th>District heating</th>
<th>Industrial</th>
<th>Human exhalation</th>
<th>Vegetation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>127.1</td>
<td>123.9</td>
<td>-3.2</td>
<td>49.2</td>
<td>10.8</td>
<td>48.4</td>
<td>5.2</td>
<td>7.8</td>
<td>2.5</td>
</tr>
<tr>
<td>Feb</td>
<td>114.9</td>
<td>124.3</td>
<td>9.4</td>
<td>49.2</td>
<td>10.8</td>
<td>48.4</td>
<td>5.2</td>
<td>7.8</td>
<td>2.9</td>
</tr>
<tr>
<td>Mar</td>
<td>110.6</td>
<td>95.2</td>
<td>-15.4</td>
<td>49.2</td>
<td>7.2</td>
<td>24.2</td>
<td>5.2</td>
<td>7.8</td>
<td>1.6</td>
</tr>
<tr>
<td>Apr</td>
<td>42.2</td>
<td>68.6</td>
<td>26.4</td>
<td>49.2</td>
<td>7.2</td>
<td>5.2</td>
<td>7.8</td>
<td>-0.8</td>
<td></td>
</tr>
<tr>
<td>May</td>
<td>62.9</td>
<td>67.6</td>
<td>4.7</td>
<td>49.2</td>
<td>7.2</td>
<td>5.2</td>
<td>7.8</td>
<td>-1.8</td>
<td></td>
</tr>
<tr>
<td>Jun</td>
<td>60.4</td>
<td>65.5</td>
<td>5.1</td>
<td>49.2</td>
<td>6.2</td>
<td>5.2</td>
<td>7.8</td>
<td>-2.9</td>
<td></td>
</tr>
<tr>
<td>Jul</td>
<td>61.0</td>
<td>65.3</td>
<td>4.3</td>
<td>49.2</td>
<td>6.2</td>
<td>5.2</td>
<td>7.8</td>
<td>-3.1</td>
<td></td>
</tr>
<tr>
<td>Aug</td>
<td>63.5</td>
<td>65.6</td>
<td>2.1</td>
<td>49.2</td>
<td>6.2</td>
<td>5.2</td>
<td>7.8</td>
<td>-2.8</td>
<td></td>
</tr>
<tr>
<td>Sep</td>
<td>71.1</td>
<td>72.7</td>
<td>1.6</td>
<td>49.2</td>
<td>13.2</td>
<td>5.2</td>
<td>7.8</td>
<td>-2.7</td>
<td></td>
</tr>
<tr>
<td>Oct</td>
<td>55.2</td>
<td>73.7</td>
<td>18.5</td>
<td>49.2</td>
<td>13.2</td>
<td>5.2</td>
<td>7.8</td>
<td>-1.7</td>
<td></td>
</tr>
<tr>
<td>Nov</td>
<td>145.6</td>
<td>125.0</td>
<td>-20.7</td>
<td>49.2</td>
<td>13.2</td>
<td>48.4</td>
<td>5.2</td>
<td>7.8</td>
<td>1.2</td>
</tr>
<tr>
<td>Dec</td>
<td>141.8</td>
<td>124.3</td>
<td>-17.5</td>
<td>49.2</td>
<td>10.8</td>
<td>48.4</td>
<td>5.2</td>
<td>7.8</td>
<td>2.9</td>
</tr>
<tr>
<td>Year</td>
<td>32.1</td>
<td>32.6</td>
<td>0.46</td>
<td>17.9</td>
<td>3.4</td>
<td>15.8</td>
<td>1.9</td>
<td>2.8</td>
<td>-0.2</td>
</tr>
</tbody>
</table>

Negative values indicated the CO$_2$ uptake by vegetation.

Fig. 3 Mean monthly course of CO$_2$ flux during 2009.

3 Conclusions

We used a simple statistical approach to estimate emissions of CO$_2$ from the urban area in Beijing. The individual contribution of different sources was also explored. We found that the main source of CO$_2$ is vehicles, which accounts for 75.5% and 38.9% of CO$_2$ emissions in summer and winter, respectively. The district heating is another significant contributor of CO$_2$ emissions, which accounted for 38.3% of CO$_2$ emissions in winter. The annual averages obtained from the statistical approach yielded an emission rate of 35.6 kg/(m$^2$·yr), which in close agreement with that from direct measurement by EC. This would imply that this simple bottom-up emission approach was a viable means to estimate CO$_2$ emissions in an urban area.

Acknowledgments

This work was supported by the Program of 100 Distinguished Young Scientist of the Chinese Academy of Sciences (No. 7-102151), the National Natural Science Foundation of China (No. 41275139). The authors would like to thank Dr. Jingjing Jia for the technical assistance with installing and maintaining the measurement equipment. The comments of the anonymous reviewers have helped substantially to improve the manuscript.

References


Tsinghua University, 2007. Air Quality Safeguards Research of Beijing During the 29th Olympic Games, Beijing. 156.


Editorial Board of Journal of Environmental Sciences

Editor-in-Chief
Hongxiao Tang
Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, China

Associate Editors-in-Chief
Jiuhui Qu
Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, China
Shu Tao
Peking University, China
Nigel Bell
Imperial College London, United Kingdom
Po-Keung Wong
The Chinese University of Hong Kong, Hong Kong, China

Editorial Board
Aquatic environment
Baoyu Gao
Shandong University, China
Maosheng Fan
University of Wyoming, USA
Chhipin Huang
National Chiao Tung University, Taiwan, China
Ng Wun Jern
Nanyang Environment & Water Research Institute, Singapore
Clark C. K. Liu
University of Hawaii at Manoa, USA
Hoykong Shon
University of Technology, Sydney, Australia
Zijian Wang
Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, China
Zhiliu Wang
The Ohio State University, USA
Yuxiang Wang
Queen’s University, Canada
Min Yang
Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, China

Atmospheric environment
Michael Schloter
German Research Center for Environmental Health, Germany
Xuejun Wang
Peking University, China
Lizhong Zhu
Zhejiang University, China
Jinmin Chen
Fudan University, China
Abdelwahid Mellouki
Centre National de la Recherche Scientifique, France
Yujing Mu
Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, China
Min Shao
Peking University, China
James Jay Schauer
University of Wisconsin-Madison, USA
Yuesi Wang
Institute of Atmospheric Physics, Chinese Academy of Sciences, China
Xin Yang
University of Cambridge, UK

Environmental biology
Yong Cai
Florida International University, USA
Jae-Young Lee
Hanyang University, South Korea
Christopher Rensing
University of Copenhagen, Denmark
Bojan Sedmak
National Institute of Biology, Ljubljana
Lirong Song
Institute of Hydrobiology, Chinese Academy of Sciences, China
Zhongxia Wang
National Natural Science Foundation of China
Gehong Wei
Northwest A & F University, China
Daqiang Yin
Tongji University, China
Zhongtang Yu
The Ohio State University, USA

Environmental toxicology and health
Jingwen Chen
Dalian University of Technology, China
Jinming Hu
Peking University, China
Guibin Jiang
Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, China
Sijin Liu
Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, China
Tsunoshi Nakanishi
Gifu Pharmaceutical University, Japan
Willie Peijnenburg
University of Leiden, The Netherlands
Bingsheng Zhou
Institute of Hydrobiology, Chinese Academy of Sciences, China

Environmental catalysis and materials
Hong He
Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, China
Junhua Li
Tsinghua University, China
Wenfeng Shangguan
Shanghai Jiao Tong University, China

Environmental analysis and method
Zongwei Cai
Hong Kong Baptist University, Hong Kong, China
Jiping Chen
Dalian Institute of Chemical Physics, Chinese Academy of Sciences, China
Minghui Zheng
Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, China

Municipal solid waste and green chemistry
Pinjing He
Tongji University, China

Environmental ecology
Rusong Wang
Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, China

Copyright © Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences. Published by Elsevier B.V. and Science Press. All rights reserved.
Aims and scope

*Journal of Environmental Sciences* is an international academic journal supervised by Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences. The journal publishes original, peer-reviewed innovative research and valuable findings in environmental sciences. The types of articles published are research article, critical review, rapid communications, and special issues.

The scope of the journal embraces the treatment processes for natural groundwater, municipal, agricultural and industrial water and wastewaters; physical and chemical methods for limitation of pollutants emission into the atmospheric environment; chemical and biological and phytoremediation of contaminated soil; fate and transport of pollutants in environments; toxicological effects of terrorist chemical release on the natural environment and human health; development of environmental catalysts and materials.

**For subscription to electronic edition**

Elsevier is responsible for subscription of the journal. Please subscribe to the journal via http://www.elsevier.com/locate/jes.

**For subscription to print edition**

China: Please contact the customer service, Science Press, 16 Donghuangchenggen North Street, Beijing 100717, China. Tel: +86-10-64017032; E-mail: journal@mail.sciencep.com, or the local post office throughout China (domestic postcode: 2-580).

Outside China: Please order the journal from the Elsevier Customer Service Department at the Regional Sales Office nearest you.

Submission declaration

Submission of a manuscript implies that the work described has not been published previously (except in the form of an abstract or as part of a published lecture or academic thesis), that it is not under consideration for publication elsewhere. The submission should be approved by all authors and tacitly or explicitly by the responsible authorities where the work was carried out. If the manuscript accepted, it will not be published elsewhere in the same form, in English or in any other language, including electronically without the written consent of the copyright-holder.

**For subscription to electronic edition**

Elsevier is responsible for subscription of the journal. Please subscribe to the journal via http://www.elsevier.com/locate/jes.

**For subscription to print edition**

China: Please contact the customer service, Science Press, 16 Donghuangchenggen North Street, Beijing 100717, China. Tel: +86-10-64017032; E-mail: journal@mail.sciencep.com, or the local post office throughout China (domestic postcode: 2-580).

Outside China: Please order the journal from the Elsevier Customer Service Department at the Regional Sales Office nearest you.

Submission declaration

Submission of a manuscript implies that the work described has not been published previously (except in the form of an abstract or as part of a published lecture or academic thesis), that it is not under consideration for publication elsewhere. The submission should be approved by all authors and tacitly or explicitly by the responsible authorities where the work was carried out. If the manuscript accepted, it will not be published elsewhere in the same form, in English or in any other language, including electronically without the written consent of the copyright-holder.

**Editorial**

Authors should submit manuscript online at http://www.jesc.ac.cn. In case of queries, please contact editorial office. Tel: +86-10-62920553, E-mail: jesc@263.net, jesc@rcees.ac.cn. Instruction to authors is available at http://www.jesc.ac.cn.

Journal of Environmental Sciences (Established in 1989)  
Vol. 25 No. 12 2013

Supervised by: Chinese Academy of Sciences  
Published by: Science Press, Beijing, China

Sponsored by: Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences  
Distributed by: Elsevier Limited, The Netherlands

Edited by: Editorial Office of Journal of Environmental Sciences  
Domestic: Science Press, 16 Donghuangchenggen North Street, Beijing 100717, China  

Printed by: Beijing Beilin Printing House, 100083, China

CN 11-2629/X  Domestic price per issue: RMB ¥ 110.00  
Domestic postcode: 2-580