



China's CO₂
emissions in
spatiotemporal

M.-M. Liu et al.

This discussion paper is/has been under review for the journal Atmospheric Chemistry and Physics (ACP). Please refer to the corresponding final paper in ACP if available.

Refined estimate of China's CO₂ emissions in spatiotemporal distributions

M.-M. Liu¹, H.-K. Wang^{1,2}, H.-M. Wang³, T. Oda^{4,5}, Y. Zhao¹, X.-H. Yang⁶,
R.-R. Zhang¹, B. Zhang¹, J. Bi^{1,2}, and J.-M. Chen³

¹State Key Laboratory of Pollution Control and Resource Reuse, School of the Environment, Nanjing University, Nanjing 210046, P.R. China

²Institute for Climate and Global Change Research, Nanjing University, Nanjing 210046, P. R. China

³International Institute for Earth System Science, Nanjing University, Nanjing 210046, P. R. China

⁴Cooperative Institute for Research in the Atmosphere, Colorado State University, Fort Collins, CO, USA

⁵Global Monitoring Division, NOAA Earth System Research Laboratory, Boulder, CO, USA

⁶Institute of Geographical Sciences & Natural Resources Research, Chinese Academy of Sciences (CAS), Beijing 100101, P. R. China

Received: 11 June 2013 – Accepted: 16 June 2013 – Published: 1 July 2013

Correspondence to: H.-K. Wang (wanghk@nju.edu.cn) and J.-M. Chen (jing.chen@utoronto.ca)

Published by Copernicus Publications on behalf of the European Geosciences Union.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Abstract

Being the largest contributor to the global source of fossil-fuel CO₂ emissions, China's emissions need to be accurately quantified and well understood. Previous studies have usually focused on the amount of national emissions and rarely discussed their spatiotemporal distributions, which are also crucial for both carbon flux and carbon management. In this study, we calculated China's CO₂ emissions from fossil fuel use and industrial processes using provincial statistics and then mapped those emissions at 0.25° resolution on monthly basis. Several key steps have been implemented to gain a better understanding of the spatiotemporal distributions, including (1) development and application of China's CO₂ emission inventories using provincial statistics; (2) separate calculations of emissions from large point sources and accurate identification of their geographical locations; (3) development of 1 km × 1 km gridded population and GDP data for China from 2000 to 2009 and application of them as dynamic spatial proxies to allocate emissions; and (4) monthly variation curves of CO₂ emissions from various sectors were developed for each province and applied to our inventory. China's total CO₂ emission from fossil fuel and industrial process have increased from 3.6 billion tons in 2000 to 8.6 billion tons in 2009, which may be off by 14–18% and are enough to skew global totals. And the resulting spatiotemporal distributions of our inventories also differed greatly in several ways from those derived using national statistics and population-based approach for the various economic development levels, industrial and energy structures, and even large point emissions sources within China and each province.

1 Introduction

CO₂ emissions, which come from combustion of fossil fuel and industrial processes, are a major input to the global carbon cycle (Gregg et al., 2008). Existing emission estimates are usually made at national and regional level on annual basis (Boden et al.,

ACPD

13, 17451–17478, 2013

China's CO₂ emissions in spatiotemporal

M.-M. Liu et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



China's CO₂ emissions in spatiotemporal

M.-M. Liu et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

2011; EIA, 2010; IEA, 2012; Olivier et al., 2011). However, previous studies have argued that existing anthropogenic CO₂ emission inventories may have potential biases (Gurney, 2005; Marland, 2012). Especially for China, a recent study revealed that an 18% gap of Chinese CO₂ emissions corresponded to approximately 1.4 billion tons, which was greater than total emissions from Japan (Guan et al., 2012). Actually, there has long been a concern about the accuracy and reliability of China's energy statistics (Sinton, 2001). Akimoto et al. (2006) suggested that there were substantial differences in energy consumption data for China between official statistics, and verified province-by-province statistics data were in better agreement with satellite observations. However, few data on CO₂ emissions estimated on a sub-national spatial scale (e.g., province and city) exist in China (Guan et al., 2012; Wang et al., 2012a; Zhao et al., 2012).

Given that it is the largest emitting country, China's total emissions have already raised great concerns worldwide. However, the uncertainties of spatiotemporal distributions of these emissions, which are crucial for both carbon management and potential future climate models (Gregg and Andres, 2008), are rarely discussed. Previous studies usually applied population density as proxy to distribute national emissions (Andres et al., 1996; Brenkert, 2003; Olivier et al., 2005). This methodology often works fairly well, but is not appropriate for explaining China's emission distribution because of the extremely uneven development and per capita emissions within the country (Wang et al., 2012a). Most existing studies quantified seasonal or monthly variations of CO₂ emissions based on monthly energy sales or consumption data (Blasing et al., 2005; Gregg and Andres, 2008; Losey et al., 2006; Rotty, 1987), which is impracticable in China because the governments do not report monthly fuel uses by sector. Therefore, monthly variation curves were usually established by weighting the monthly fractions of national thermal electricity generation or value of industrial outputs (Gregg et al., 2008; Streets, 2003). However, results for monthly variations of CO₂ emissions over years in China are still scarce, especially at the sub-national level.

China's CO₂ emissions in spatiotemporal

M.-M. Liu et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



sumption. As Chinese official statistics report only road transport fuel consumption caused by commercial activity, this study calculated fuel use by road transportation as the product of vehicle mileage traveled and the relevant fuel economy. Data on vehicle populations were taken from the Statistical Yearbooks (NBSC, 2001–2010b) for each province. Vehicle mileage travelled (VMT) and fuel economy (FE) data were taken from previous studies (Wang et al., 2010, 2011). Industrial products were taken from the statistical yearbooks for each province and the China Cement Yearbook. In contrast to previous studies, this study substituted cement production with clinker production in order to calculate CO₂ emissions from the cement industrial process.

Using Crystal Ball, the Monte Carlo stochastic simulation approach was employed to model probability distributions of key input parameters, and uncertainties estimated. Activity data (AD), such as energy consumption and industrial production, are primarily from two sources: China's provincial statistics and national statistics, which don't match well. A triangular distribution function is assumed for AD data for limited samples (Brinkman et al., 2005; Wu et al., 2010). The national data point was set as the minimum value, and then the maximum value was calculated by adding up the provincial AD data and absolute difference between provincial and national statistics. Table S1 summarized the key characteristics of distribution function curves for EFs. Monte Carlo sampling number was set as 10 000.

2.2 Temporal variation

Industrial energy consumption (IEC) and industrial processes (INP) are the largest two contributors, accounting respectively 74 % and 11 % of China's total anthropogenic CO₂ emissions. Temporal variations of emissions from these two sectors are also significant, especially for IEC. Previous studies have shown that emissions from the combustion of liquid fuels, which are mainly consumed by transportation, are relatively constant throughout the year (Gregg and Andres, 2008). Thus, monthly variations of total CO₂ emissions are dominated by those of IEC and INP. As CO₂ emission factors changed little for specific energy type throughout the year, monthly variation of

emission is consistent with that of AD, such as energy consumptions and industrial productions.

Monthly variations of IEC's emissions in various provinces were estimated on the following assumptions: (1) monthly variations of emissions from electricity generation and combustion during steel production are consistent with the variation of respective productions. Monthly thermal power generation and steel production are available in provincial statistics (NBSC, 2001–2010b); (2) because the data on monthly heat production are not available in China, we assumed heat consumption is equal to the production. Monthly variations of residential and industrial heat consumptions are respectively indicated by the variations of residential energy use (Streets, 2003) and industrial added value (NBSC, 2001–2010b); and (3) monthly industrial added values (NBSC, 2001–2010b) were used as proxy to reflect variations of emissions from other industries. Similarly, monthly variation curves of emissions from INP sector were established using monthly industrial production (e.g. cement and steel production).

2.3 Spatial distribution

As power plants accounted for nearly 30 % of China's total emissions (Zhao et al., 2012) and cement production accounted for 60 % of emissions from INP, we mapped those emissions as large point sources (LPS) and identify their locations exactly by latitude and longitude. Power plants ranking in the top 80 % in terms of electricity production (CEC, 2000–2009) and cement plants with capacity above 1 M tyr^{-1} (ACC, 2003, 2006; CCTEN, 2009) were selected as LPS in this study. We derived the geographical coordinate of LPS by checking their addresses with Google Earth. Some LPS that could not be identified for lack of information were included in area emissions. For example, 861 LPS, which emitted 2304 million tons CO_2 , have been separately calculated in 2009. However, geographical coordinate of 40 LPS accounting for 3.78 % of the total LPS emissions were not available and were treated as area sources.

The emissions from other sources (except LPS) were treated as area emission and allocated to each grid at 0.25° resolution via the proxies of population and/or GDP

China's CO_2 emissions in spatiotemporal

M.-M. Liu et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



and largest power base, grids with higher emissions have also obviously appeared during the past decade. Significant decreases of emissions are usually due to the elimination or reduction of LPS with outdated technologies in the past decade in some cells (Zhang et al., 2009; Zhao et al., 2013).

5 Spatial distribution characteristics of our refined CO₂ emission inventories were found to be obviously different with CDIAC (one the most widely used dataset of anthropogenic CO₂ emissions inventory) (Fig. 6). There are three explanations for such great differences.

10 *First*, our basic emission inventory was developed using provincial statistics and then aggregated to get national emissions. Therefore, on one hand, China's total CO₂ emissions are different among various studies as illustrated in Fig. 3; on the other hand, comparing with previous studies, e.g. CDIAC (Andres et al., 2011a), ODIAC (Oda and Maksyutov, 2011) and FFDAS (Rayner et al., 2010), using the national total as the basic emissions inventory to allocate into various provinces and locations, our inventories are directly calculated at provincial levels, thus definitely different with them at the provincial resolution.

15 *Second*, except for various absolute emissions, another important reason for the spatial differences between our results and CDIAC's is the process of LPS. As shown in Figs. 6 and 7b, most cells with a ratio greater than 1.5 contained LPS, but emissions from LPS are included in area sources and allocated to all cells using the proxy of population in CDIAC. However, the emissions from LPS are usually intense and poorly correlated with population (Oda and Maksyutov, 2011). Most LPS are situated in eastern China (Fig. 7), and CO₂ emissions from large coal-fired power plants accelerated from 2000 to 2009, especially in the province of NM (Inner Mongolia) as we illustrated above. Our selected LPS contributed over 25 % of national total emissions and the fractions exceeded 35 % for some individual provinces like Anhui, Guizhou, Ningxia, Zhejiang (Table S5). It means that 25–35 % of total emissions have been accurately allocated in the geographical locations, which greatly improves the spatial resolution of our inventory.

China's CO₂ emissions in spatiotemporal

M.-M. Liu et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



China's CO₂ emissions in spatiotemporal

M.-M. Liu et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Third, the application of population density as a spatial proxy to distribute China's CO₂ emissions will inevitably introduce uncertainties in CDIAC. As per capita emissions vary greatly across different provinces (Fig. 3b), due to unbalanced regional development, it is not surprising that large errors are introduced when population is used as a proxy to allocate emissions in various areas. Special policy and development characteristics in some provinces (such as Beijing and Inner Mongolia) of China also make their emission trends very different from others (Fig. 3), which further influence the spatial distributions of emissions. Furthermore, CDIAC assumed little change in spatial density of population and used population density data of 1984 (Andres et al., 1996, 2011a) to distribute CO₂ emissions for all other years. This means that fractions of each grid emissions to the total emissions remain the same in different years, which are equal to the fraction of each grid population to the total population in 1984. This assumption is proper for the developed countries with little change in the spatial distribution of population. However, it will lead to serious problems where there is rapid urbanization as in China (Yusuf, 2008; Zhang and Song, 2003), which has had great changes in the population and thus emissions distribution in recent years (Fig. S4).

3.3 Temporal distribution

China's total CO₂ emissions show strong seasonal variations with a peak in December and a significant valley from January to February for all years (except 2008) (Fig. 8). Increased energy consumption to meet electricity demand for air conditioning and heating demand leads to higher CO₂ emissions in December. However, it could also be a result of data manipulation to meet annual quotas by the end of the year to meet annual energy conservation targets or to match economic development (Gregg et al., 2008; Guan et al., 2012). Industrial activities usually stop for several days during the period January–February for traditional Chinese holidays of Spring Festival, which lead to the reduction of CO₂ emissions. It should be noted that fractions of heating-related emissions in northern provinces of China were very high during January to February, such as Heilongjiang and Beijing. However, the heating effect on the variation of na-

China's CO₂ emissions in spatiotemporal

M.-M. Liu et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



tional total emissions is very small because it contributes only about 1 % to total CO₂ emissions in China. Therefore, our monthly variations curve of China's total CO₂ emissions is similar to that of CDIAC before 2005. But obvious differences were found since 2006, especially for the year 2008, which could be explained by the fact that monthly fuel consumption data in 2008 was estimated via Monte Carlo methods in CDIAC (Andres et al., 2011b). However, monthly variations of national emissions in 2008 were very different as compared with other years for the following reasons: (1) significant reduction in industrial activities and hence CO₂ emissions in China in second half of the year could have been caused by global financial crisis that started since September of 2008 (Fig. S5); and (2) measures for controlling or shutting down energy intensive and heavy polluting industries in Beijing and the surrounding areas during 2008 Olympic Games (Sect. 3.1) also reduced CO₂ emissions in the summer of this year.

We developed monthly emission curves at China's provincial levels (Fig. 8b), and found each province has its own characteristics in monthly variations of CO₂ emissions which can differ greatly with the national average. For example, the impact of reducing industrial activities during the Spring Festival is smaller on Beijing, Shanghai and Heilongjiang than on other provinces. As heating contributed nearly 8 % to Heilongjiang's total CO₂ emissions, which is well above national average level of 1 %, growing heating consumptions in these two months have offset the impact of reducing industrial activity. For Beijing and Shanghai, tertiary industries, which respectively accounted for nearly 75 % and 60 % of their GDP, become more prosperous during the Spring Festival, and increased emissions from tertiary industry offset the impact of industrial activity reductions. Another example is the different power generation structures among various provinces. Hydropower is second in importance to thermal power, accounted for 16.6 % (NBSC, 2001–2010b) of total electricity generation in 2009. However, it is significantly limited by the precipitation, which is influenced by the monsoonal climate and varies greatly from province to province and season to season. Therefore, thermal power will be adapted to the variation of hydropower to meet electricity demand. As shown in Fig. 9, summer contributed over 25 % of annual CO₂ emissions

China's CO₂ emissions in spatiotemporal

M.-M. Liu et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



from electricity generation for most provinces in China. However, the situations differed in some provinces with a larger proportion of hydropower (Lindner et al., 2013), such as Yunnan, Guangxi, Sichuan, Qinghai, Hubei and Fujian. As high rainfall in summer brings abundant hydropower resources, thermal electricity production and thus CO₂ emissions from thermal power plants are reduced. Therefore, application of national average temporal variation curves would cover the differences among various provinces in China which may have an impact on atmospheric carbon concentration simulation (Gurney et al., 2005).

3.4 Uncertainties in spatial distributions

The most important step (except the calculation of provincial and sectoral CO₂ emissions, which has already been discussed in Sects. 3.1 and 3.2) to reduce uncertainty in spatial distributions of our emission inventory is the separate calculation of emissions from LPS. We comprehensively checked the address of each LPS on various materials, which include internet and other available materials (ACC, 2003, 2006; CCTEN, 2009; CEC, 2000–2009). However, if the information about LPS is not accurate enough, errors will be introduced to the spatial distribution of emission, although the regional total is unaffected.

Comparing with CARMA dataset (www.carma.org), which has already been applied (Oda and Maksyutov, 2011; Wang et al., 2012b) in calculating emissions from global power plants, the following points should be stressed: (1) CARMA only provides data for 2000, 2004, 2007 and 2009, which introduces significant uncertainty when extend emissions to other years for rapid development of new power plants with advanced technologies and elimination of old ones with outdated technologies in China; (2) CO₂ emissions from power plants are 3.12 billion tons in 2007 using CARMA dataset, accounting for over 40 % of China's total emissions, which is much higher than our and other published results (25–35 %) (Zhao et al., 2012). Estimates of emissions from China's individual plants in CARMA (Table S6) also show great differences with our localized results (Table S7); and (3) CARMA dataset provides city center as the location

of a reported power plant and could introduce big spatial errors (Table S7) comparing to our LPS database, which mapped emissions to the big chimneys of 80 % of the power plants (Fig. S6). Therefore, it should be cautious when CARMA dataset were applied to estimate emissions of power plants in China.

5 As county is China's basic statistical administrative unit and is comparable to the spatial resolution (0.25°) in our work, it seems more reasonable to develop the inventory at 0.25° resolution based on current existing datasets. Cautions should be paid if a higher resolution inventory, like ODIAC (1 km resolution), is developed, because every tiny error for an individual LPS and even small point sources will impact emissions in
10 such small grids. And only evaluation of LPS (assumed no errors or omissions) is not enough to produce such high resolution inventories for China. Furthermore, original national emissions inventory, or even our provincial inventory, with some proxies may also introduce greater uncertainties when higher resolution inventories are developed.

4 Conclusions

15 New inventories of China's CO₂ emissions of fossil fuel consumption and industrial process from 2000 to 2009 at 0.25° resolution are developed using provincial statistical data and our large point sources dataset. We estimate China's total CO₂ emission from fossil fuel consumption and industrial process reach 8.6 billion tons in 2009, which is 2.4 times that in 2000. And several keys steps have been implemented to gain a better
20 understanding of the spatiotemporal distributions of China's emissions, including (1) development and application of China's CO₂ emission inventories, which are based on provincial statistics; (2) separate calculations of emissions from large point sources and accurate identification their geographical locations; (3) development of 1 km × 1 km gridded population and GDP data for China from 2000 to 2009 and application of them
25 as dynamic spatial proxies to distribute the emissions; and (4) monthly variation curves of CO₂ emissions from various sectors were developed for each province and applied to

China's CO₂ emissions in spatiotemporal

M.-M. Liu et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



our inventory. Except the absolute emissions, great uncertainties in the spatiotemporal distributions of China's CO₂ emissions were also found in this study.

Although we thought China's CO₂ emissions and their spatiotemporal distributions were refined comparing with previous studies, there could still be large uncertainties remaining in individual locations. This is because emissions are estimated at the provincial level, while emission patterns may vary within a province due to local differences in economic and industrial structures and large point sources. To develop higher resolution inventories, therefore, the emissions from more point sources should be determined and estimated individually, and original emissions inventories at finer regional scales, such as the city level (Wang et al., 2012a), using more region-specific activity data/emission factors are also required. Furthermore, the applications of various data sources (e.g. satellite NO₂ data) to verify and improve the accuracy of time series in our inventory should be further processed in future study.

Supplementary material related to this article is available online at:

<http://www.atmos-chem-phys-discuss.net/13/17451/2013/acpd-13-17451-2013-supplement.pdf>.

Acknowledgements. This work was supported by China National Program on Key Basic Research Project (973 Program, Project No. 2010CB950704), China National Nature Science Foundation (Project No. 51008155) and Foundation Research Project of Jiangsu Province (The Natural Science Fund No. BK2011017). The contents of this paper are solely the responsibility of the authors and do not necessarily represent official views of the sponsors.

References

ACC: China Cement Industry Enterprise Indirectory, China Building Materials Press, 2003, Beijing, 2006.

ACC: China Cement Almanac 2010, Jiangsu People's Publishing House, Nanjing, 2011.

China's CO₂ emissions in spatiotemporal

M.-M. Liu et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



China's CO₂ emissions in spatiotemporal

M.-M. Liu et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Akimotoa, H., Oharaa, T., Kurokawac, J.-I., and Horii, N.: Verification of energy consumption in China during 1996–2003 by using satellite observational data, *Atmos. Environ.*, 40, 7663–7667, 2006.

Andres, R. J., Marland, G., Fung, I., and Matthews, E.: A 1° × 1° distribution of carbon dioxide emissions from fossil fuel consumption and cement manufacture, 1950–1990, *Global Biogeochem. Cy.*, 10, 419–429, 1996.

Andres, R. J., Boden, T., and Marland, G.: Annual fossil-fuel CO₂ emissions: isomass of emissions gridded by one degree latitude by one degree longitude, Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, US Department of Energy, Oak Ridge, Tenn., USA, doi:10.3334/CDIAC/ffe.Annualsommass.2011, 2011a.

Andres, R. J., Gregg, J. S., Losey, L., Marland, G., and Boden, T. A.: Monthly, global emissions of carbon dioxide from fossil fuel consumption, *Tellus B*, 63, 309–327, 2011b.

Blasing, T. J., Bronniak, C. T., and Marland, G.: The annual cycle of fossil-fuel carbon dioxide emissions in the United States, *Tellus*, 57, 107–115, 2005.

Boden, T., Marland, G., and Andres, R.: Global, regional, and national fossil-fuel CO₂ emissions, Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, US Department of Energy, Oak Ridge, Tenn., USA, 2011.

Brenkert, A. L.: Carbon dioxide emission estimates from fossil-fuel burning, hydraulic cement production, and gas flaring for 1995 on a one degree grid cell basis, Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Tenn., USA, doi:10.3334/CDIAC/ffe.ndp058.2003, 2003.

Brinkman, N., Wang, M., Weber, T., and Darlington, T.: Well-to-wheels analysis of advanced fuel/vehicle systems – a North American study of energy use, greenhouse gas emissions, and criteria pollutant emissions, Argonne Natl. Lab, Argonne, IL, USA, 2005.

CCTEN: China Cement Industry Enterprise Indirectory, China News Press, Beijing, 2009.

CEC: Compilation of Statistics on the Electric Power Industry, China Electricity Council, 2000–2009.

Clark, W. W. and Isherwood, W.: Energy strategies study report for Inner Mongolia Autonomous Region, *Util. Pol.*, 18, 11–12, 2010a.

Clark, W. W. and Isherwood, W.: Inner Mongolia Autonomous Region (IMAR) energy base: additional final report and recommendations, *Util. Pol.*, 18, 13–28, 2010b.

EIA: International Energy Statistics, US Energy Information Administration (EIA), Washington, D.C., available at: <http://www.eia.gov/environment/data.cfm>, 2010.

China's CO₂ emissions in spatiotemporal

M.-M. Liu et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



- Gregg, J. S. and Andres, R. J.: A method for estimating the temporal and spatial patterns of carbon dioxide emissions from national fossil-fuel consumption, *Tellus B*, 60, 1–10, 2008.
- Gregg, J. S., Andres, R. J., and Marland, G.: China: emissions pattern of the world leader in CO₂ emissions from fossil fuel consumption and cement production, *Geophys. Res. Lett.*, 35, L08806, doi:10.1029/2007GL032887, 2008.
- Guan, D., Liu, Z., Geng, Y., Lindner, S., and Hubacek, K.: The gigatonne gap in China's carbon, *Nat. Clim. Change*, 2, 672–675, 2012.
- Gurney, K. R., Chen, Y. H., Maki, T., Kawa, S. R., Andrews, A., and Zhu, Z.: Sensitivity of atmospheric CO₂ inversions to seasonal and interannual variations in fossil fuel emissions, *J. Geophys. Res.*, 110, D10308, doi:10.1029/2004JD005373, 2005.
- IEA: CO₂ Emissions from Fuel Combustion (2012 edn.), International Energy Agency, Paris, France, available at: <http://www.iea.org/publications/freepublications/publication/name,32870,en.html>, 2012.
- IPCC (Intergovernmental Panel on Climate Change): 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, edited by: Eggleston, H. S., Buendia, L., Miwa, K., Ngara, T., and Tanabe, K., IGES: Japan, 2006.
- Lindner, S., Liu, Z., Guan, D., Geng, Y., and Li, X.: CO₂ emissions from China's power sector at the provincial level: consumption versus production perspectives, *Renew. Sust. Energ. Rev.*, 19, 164–172, 2013.
- Liu, H., Jiang, D., Yang, X., and Luo, C.: 1 km gridded GDP database of China based on GIS, *Geo-Inf. Sci.*, 7, 120–123, 2005.
- Losey, L. M., Andres, R. J., and Marland, G.: Monthly estimates of carbon dioxide emissions from fossil-fuel consumption in Brazil during the late 1990s and early 2000s, *Area*, 38, 445–452, 2006.
- Marland, G.: Emissions accounting: China's uncertain CO₂ emissions, *Nat. Clim. Change*, 2, 645–646, 2012.
- NBSC: China Energy Statistical Yearbook, Beijing, China Statistics Press, 2001–2010a.
- NBSC: China Statistical Yearbook, Beijing, China Statistics Press, 2001–2010b.
- Oda, T. and Maksyutov, S.: A very high-resolution (1 km × 1 km) global fossil fuel CO₂ emission inventory derived using a point source database and satellite observations of nighttime lights, *Atmos. Chem. Phys.*, 11, 543–556, doi:10.5194/acp-11-543-2011, 2011.

**China's CO₂
emissions in
spatiotemporal**

M.-M. Liu et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



- Olivier, J. G. J., Van Aardenne, J. A., Dentener, F. J., Pagliari, V., Ganzeveld, L. N., and Peters, J. A. H. W.: Recent trends in global greenhouse gas emissions: regional trends 1970–2000 and spatial distribution of key sources in 2000, *Environ. Sci.*, 2, 81–99, 2005.
- Olivier, J. G. J., Janssens, M., Peters, J., and Julian, W.: Long-term trend in global CO₂ emissions, PBL Netherlands Environmental Assessment Agency (PBL), Bilthoven, the Netherlands, PBL Report 500253004, 2011.
- Peters, G. P., Marland, G., Le Quéré, C., Boden, T., Canadell, J. G., and Raupach, M. R.: Rapid growth in CO₂ emissions after the 2008–2009 global financial crisis, *Nat. Clim. Change*, 2, 2–4, 2011.
- Rayner, P., Raupach, M., Paget, M., Peylin, P., and Koffi, E.: A new global gridded dataset of CO₂ emissions from fossil fuel combustion: methodology and evaluation, *J. Geophys. Res.*, 115, D19306, doi:10.1029/2009JD013439, 2010.
- Rotty, R. M.: Estimates of seasonal variation in fossil fuel CO₂ emissions, *Tellus B*, 39, 184–202, 1987.
- Sinton, J. E.: Accuracy and reliability of China's energy statistics, *China Econ. Rev.*, 12, 373–383, 2001.
- Streets, D. G.: An inventory of gaseous and primary aerosol emissions in Asia in the year 2000, *J. Geophys. Res.*, 108, 8809, doi:10.1029/2002JD003093, 2003.
- Wang, H., Fu, L., Zhou, Y., Du, X., and Ge, W.: Trends in vehicular emissions in China's mega cities from 1995 to 2005, *Environ. Pollut.*, 158, 394–400, 2010.
- Wang, H., Fu, L., and Bi, J.: CO₂ and pollutant emissions from passenger cars in China, *Energ. Policy*, 39, 3005–3011, 2011.
- Wang, H., Zhang, R., Liu, M., and Bi, J.: The carbon emissions of Chinese cities, *Atmos. Chem. Phys.*, 12, 6197–6206, doi:10.5194/acp-12-6197-2012, 2012.
- Wang, R., Tao, S., Ciais, P., Shen, H. Z., Huang, Y., Chen, H., Shen, G. F., Wang, B., Li, W., Zhang, Y. Y., Lu, Y., Zhu, D., Chen, Y. C., Liu, X. P., Wang, W. T., Wang, X. L., Liu, W. X., Li, B. G., and Piao, S. L.: High resolution mapping of combustion processes and implications for CO₂ emissions, *Atmos. Chem. Phys. Discuss.*, 12, 21211–21239, doi:10.5194/acpd-12-21211-2012, 2012.
- Wu, Y., Streets, D., Wang, S., and Hao, J.: Uncertainties in estimating mercury emissions from coal-fired power plants in China, *Atmos. Chem. Phys.*, 10, 2937–2946, doi:10.5194/acp-10-2937-2010, 2010.

- Xinhua News Agency: Experts suggest energy base in Inner Mongolia, available at: <http://english.cri.cn/2946/2008/01/02/198@310056.htm>, 2008.
- Yang, X., Huang, Y., Dong, P., Jiang, D., and Liu, H.: An updating system for the gridded population database of China based on remote sensing, GIS and spatial database technologies, *Sensors*, 9, 1128–1140, 2009.
- Yusuf, S.: China urbanizes: consequences, strategies, and policies, World Bank Publications, Washington, DC, USA, 2008.
- Zhang, K. H. and Song, S.: Rural–urban migration and urbanization in China: evidence from time-series and cross-section analyses, *China Econ. Rev.*, 14, 386–400, 2003.
- Zhang, Q., Streets, D. G., Carmichael, G. R., He, K. B., Huo, H., Kannari, A., Klimont, Z., Park, I. S., Reddy, S., Fu, J. S., Chen, D., Duan, L., Lei, Y., Wang, L. T., and Yao, Z. L.: Asian emissions in 2006 for the NASA INTEX-B mission, *Atmos. Chem. Phys.*, 9, 5131–5153, doi:10.5194/acp-9-5131-2009, 2009.
- Zhao, Y., Nielsen, C. P., and McElroy, M. B.: China’s CO₂ emissions estimated from the bottom up: recent trends, spatial distributions, and quantification of uncertainties, *Atmos. Environ.*, 59, 214–223, 2012.
- Zhao, Y., Zhang, J., and Nielsen, C. P.: The effects of recent control policies on trends in emissions of anthropogenic atmospheric pollutants and CO₂ in China, *Atmos. Chem. Phys.*, 13, 487–508, doi:10.5194/acp-13-487-2013, 2013.

**China’s CO₂
emissions in
spatiotemporal**

M.-M. Liu et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



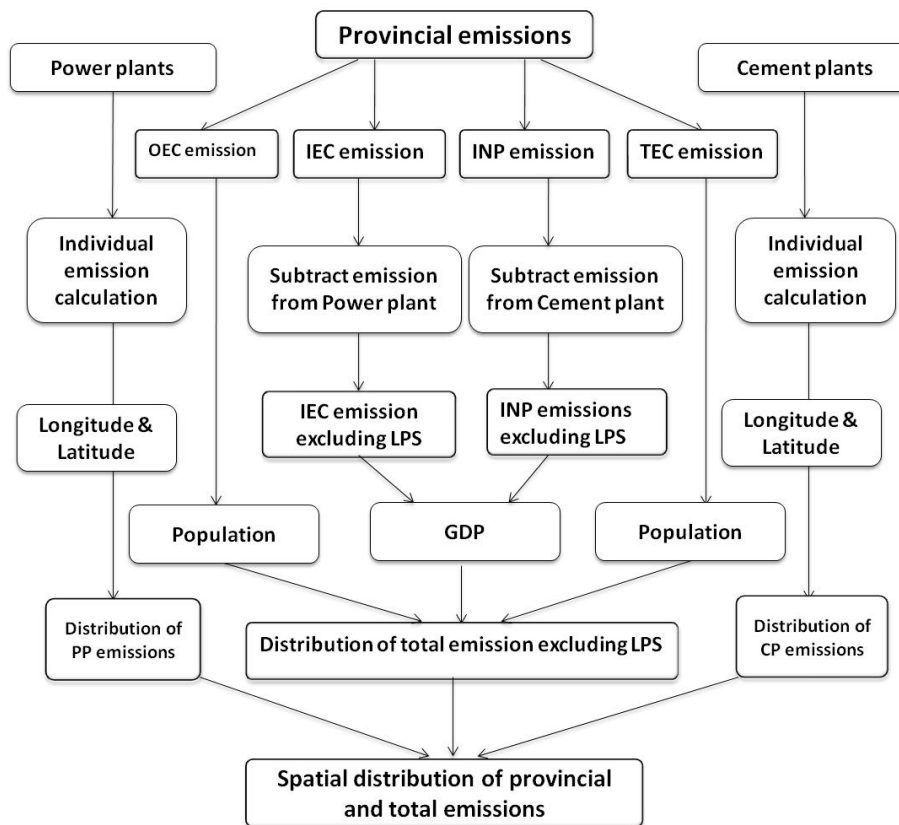


Fig. 1. Schematic methodology for the development of spatial distributions.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



China's CO₂ emissions in spatiotemporal

M.-M. Liu et al.

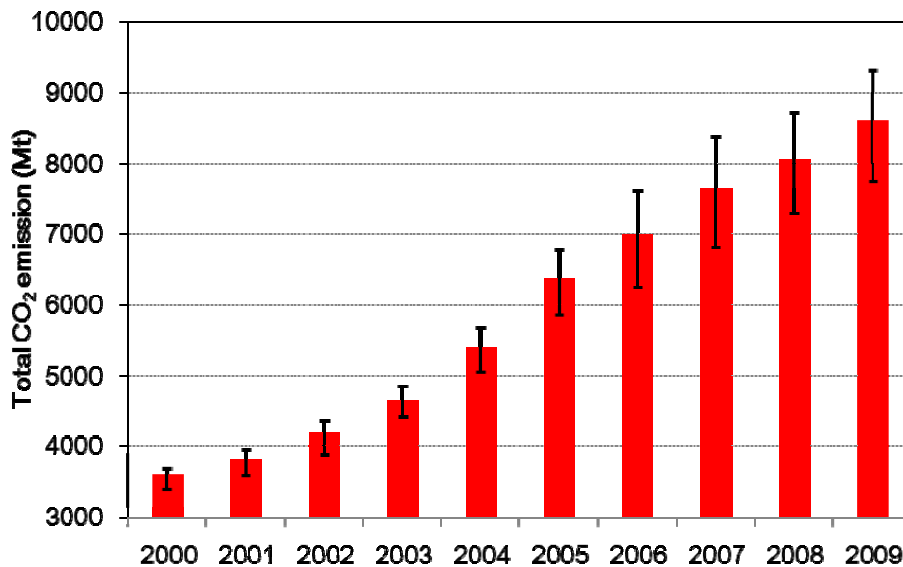


Fig. 2. Total CO₂ emissions of fossil fuel consumption and industrial process in China from 2000 to 2009.

[Title Page](#)[Abstract](#)[Introduction](#)[Conclusions](#)[References](#)[Tables](#)[Figures](#)[◀](#)[▶](#)[◀](#)[▶](#)[Back](#)[Close](#)[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)

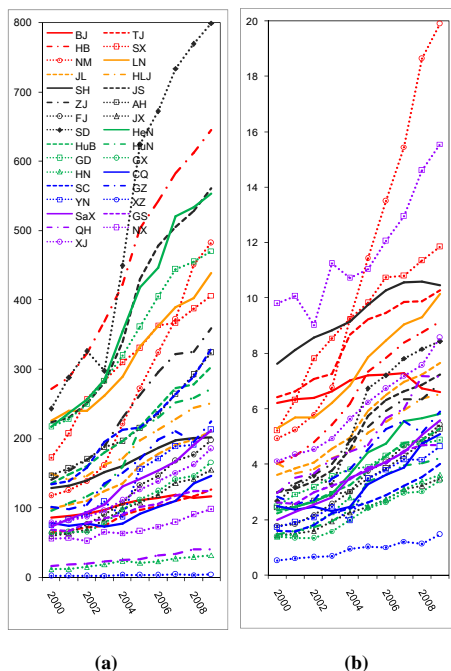


Fig. 3. CO₂ emissions of 31 provinces and municipalities in China: **(a)** total emissions, million tons; **(b)** per capita emissions, tperson⁻¹. Shandong, Hebei, Jiangsu, Henan, Guangdong, Liaoning, Shanxi, Inner Mongolia, Zhejiang and Anhui were the ten provinces that contributed most to accumulated CO₂ emissions from 2000 to 2009. They emitted 36.5 billion tons of CO₂, which accounted for 61.5% of total Chinese emissions during that period. As the largest CO₂ emitting province, Shandong itself contributed 8.7% of China's total emissions from 2000 to 2009, with an AAGR of 14% (second only to Inner Mongolia). Inner Mongolia was the seventh largest contributor to accumulated CO₂ emissions, but had the highest AAGR at 17% during the past decade. Geographical locations and abbreviations for the 31 provinces in China's mainland were shown in Fig. S1.

China's CO₂ emissions in spatiotemporal

M.-M. Liu et al.

Title Page

Abstract Introduction

Conclusions References

Tables Figures

◀ ▶

◀ ▶

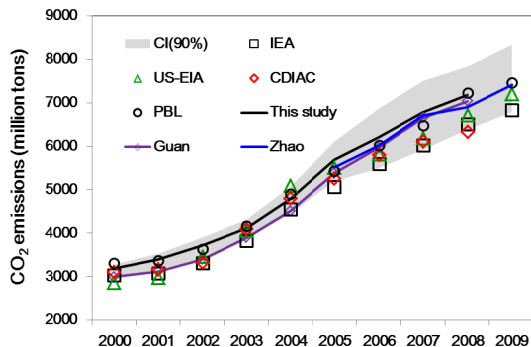
Back Close

Full Screen / Esc

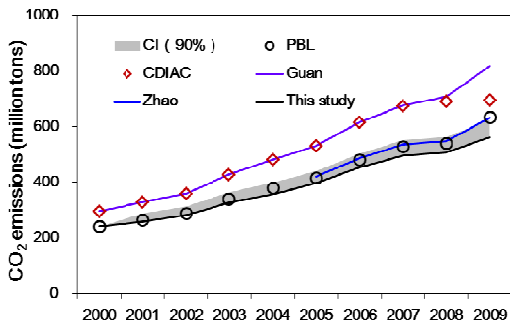
Printer-friendly Version

Interactive Discussion





(a) Fossil fuel

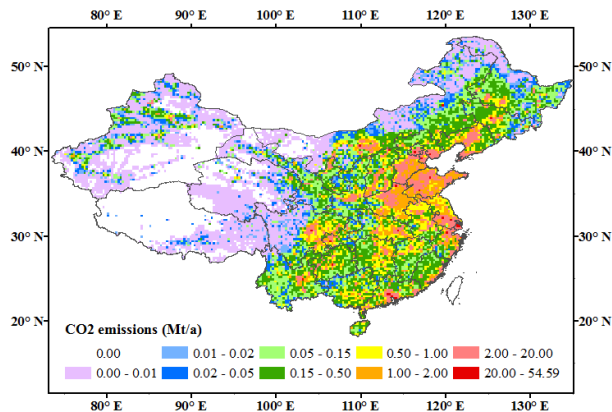


(b) Cement production process

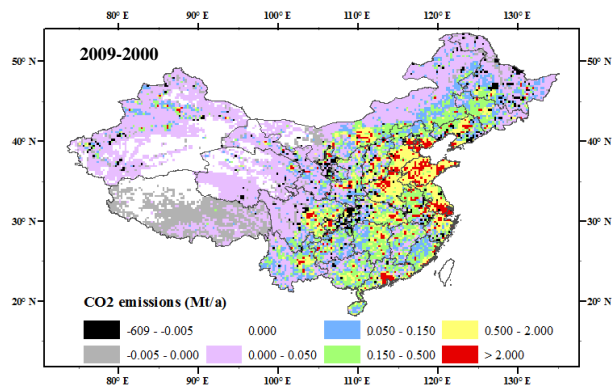
Fig. 4. Comparison of China's CO₂ emissions among various datasets: **(a)** emissions of fossil fuel; **(b)** emissions from cement productions. It should be noted that different datasets include different components in total emissions, e.g. CDIAC, IEA and PBL data omit emissions from fossil fuel use for international bunker (EFFIB), but EIA country-level data include EFFIB by incorporating the country of purchase). We excluded EFFIB and gas flaring emissions from the national total emissions in various data sets to ensure the results to be comparable.

China's CO₂
emissions in
spatiotemporal

M.-M. Liu et al.



(a) Spatial distributions in 2009



(b) Variations of emissions from 2000 to 2009

Fig. 5. Spatial distributions (0.25° resolution) and changes (2000–2009) of CO₂ emissions from energy consumption and industrial process in China. **(a)** Spatial distributions in 2009; **(b)** variations of emissions from 2000 to 2009.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



China's CO₂
emissions in
spatiotemporal

M.-M. Liu et al.

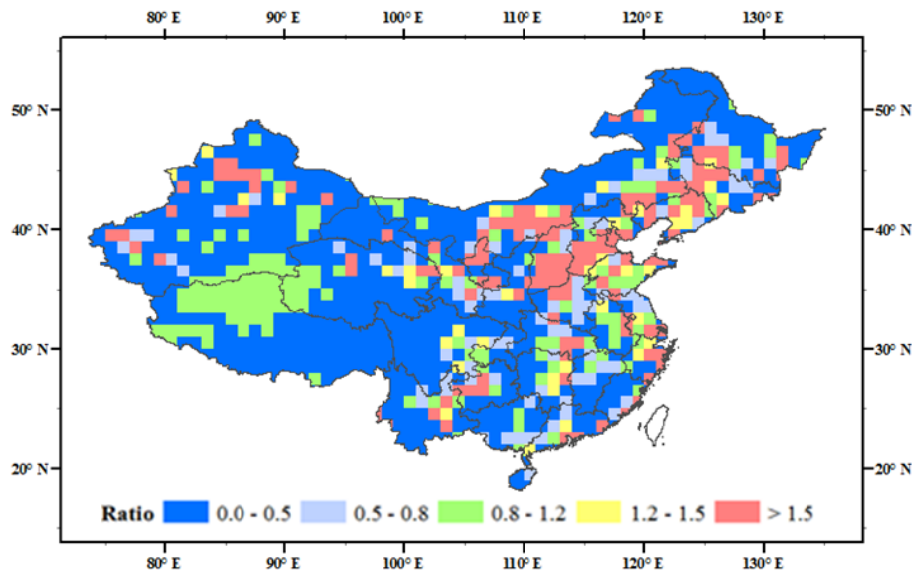


Fig. 6. Distribution of emission ratios between our results and CDIAC's at 1° resolution for year 2005. A ratio of 1 indicates that our results are equal to CDIAC, ratios larger than 1 indicate that our analysis are higher in certain grids, and ratios less than 1 indicate our analysis are lower. The ratios of cells having zero emissions in CDIAC and larger than zero emissions in our results are defined to be 100.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



China's CO₂ emissions in spatiotemporal

M.-M. Liu et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

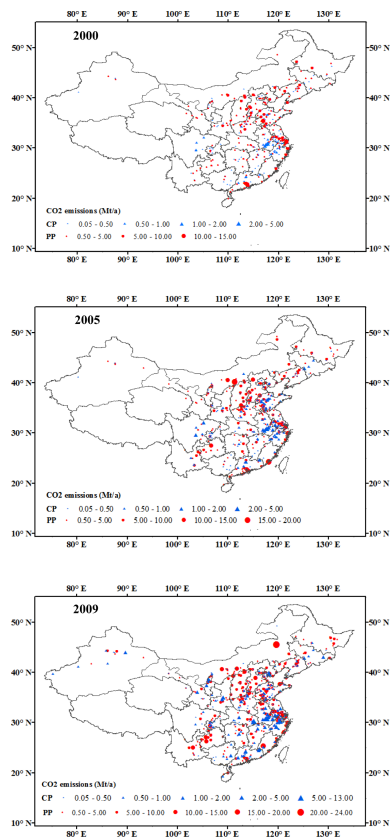


Fig. 7. Geographical locations and CO₂ emissions of the large point sources. Red circles are emissions from power plants and blue triangles are emissions from the non-combustion processes of cement plants. The bigger the size is, the more annual CO₂ emissions are. The number of LPS has increased from 240 in 2000 to 821 in 2009 (Table S5) and their emissions in each province also increased.

China's CO₂ emissions in spatiotemporal

M.-M. Liu et al.

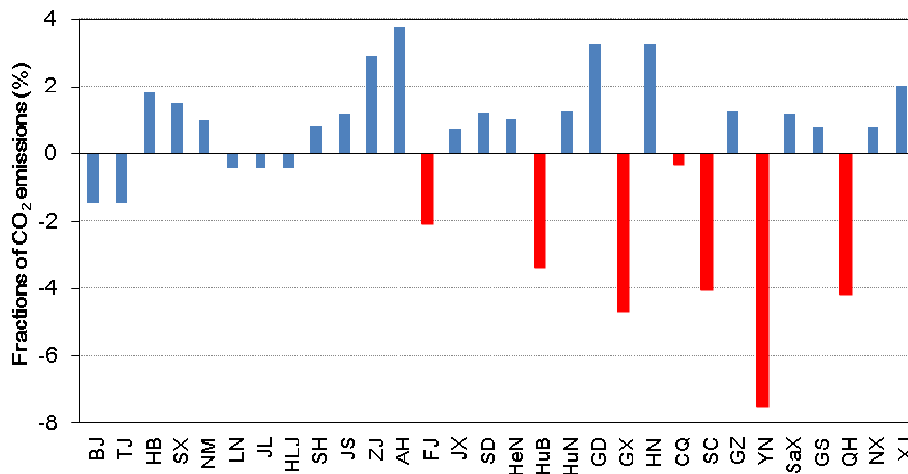


Fig. 9. Fraction (compared to 25%) of CO₂ emissions from electricity generation for 31 provinces in the summer (June, July and August) of 2009.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

