Journal: ACP
Title: High resolution mapping of combustion processes and implications for CO2 emissions
Author(s): R. Wang, S. Tao, P. Ciais, H.Z. Shen, Y. Huang, H. Chen, G.F. Shen, B. Wang, W. Li, Y.Y. Zhang, Y. Lu, D. Zhu, Y.C. Chen, X.P. Liu, W.T. Wang, X.L. Wang, B.G. Li, W.X. Liu, and S.L. Piao
MS No.: acp-2012-405
MS Type: Research Article

Reviewer 2 - Anonymous Referee, C7457

Comment 1

Although the work that is presented in this paper is very interesting and important for the CO2 modeling community, I think that the authors selected the wrong journal. A large amount of bookkeeping leads to a detailed map of CO_2 emissions (PKU-CO2). I have very little questions about the validity of the methods used. However, real scientific innovation is difficult to find.

Response

It is true that we have paid huge effort on data compiling. Still, the scientific finding of this study can be summarized as follows:

1. Recently, the importance of emission inventories at sub-national level (e.g. counties) was confirmed in many studies (*Zhang et al., 2007; Gurney et al., 2009; Wang et al.,2012*). In this paper, we attempted to carry out the sub-national disaggregation at global scale in as many countries as possible, and demonstrated that the within-country spatial variation in per-capita fuel consumption can be characterized for large countries, so that the spatial disaggregation bias induced by using national data can be reduced substantially by collecting sub-national data instead. Consequently, the spatial accuracy for these sectors (these defined in Group 8) can be enhanced correctly, and it has important implications for carbon inversion study and carbon-related policies (urbanization). Here, we want to recommend this method to the community of emission inventories.
2. The high-resolution mapping enable us to study the detailed spatial variation of CO_2 emission. One important finding of this application was that per capita CO_2 emission in urban settlements of developing countries is close to that of developed countries, suggesting a strong potential for emission increase in the future, associated with urbanization trends in the developing countries.
3. The fuel consumption inventory can not only be used for CO_2 emission computation, but is also critical for developing emission inventories of many air pollutants from combustion sources such as primary PM, BC, CO, SO_2, NOx, PAHs, Hg, and many more. In fact, several inventories (BC, PAHs, and SO_2) based on this database in already on the way. After the publication, the dataset will be made available to other researchers. Therefore, we believe that this paper can be useful in both climate and atmospheric fields.

Reference

Zhang, Y. X., Tao, S., Cao, J., and Coveney, R. M.: Emission of polycyclic aromatic hydrocarbons in China by county. Environ. Sci. Technol., 41, 683-687, 2007.
Gurney, K. R., Mendoza, D. L., Zhou, Y., Fischer, M. L., Miller, C. C., Geethakumar, S., and dela Rue du Can, S.: High resolution fossil fuel combustion CO 2 emission fluxes for the United States, Environ. Sci. Technol., 43, 5535-5541, 2009.
Wang, R., Tao, S., Wang, W.T., et al.: Black Carbon Emissions in China from 1949 to 2050. Environ. Sci. Technol. , 46, 7595 - 7603, 2012.

Comment 2

The fact that in developing countries energy use differs widely from city to rural areas is interesting. But the application to biosphere inversions is not new.

P Peylin, S Houweling, M C Krol, Karstens, U., denbeck, C. R., Geels, C., Vermeulen, A., et al. (2011). Importance of fossil fuel emission uncertainties over Europe for CO_2 modeling: model intercomparison. Atmospheric Chemistry and Physics.

This article is not even in the reference list. Simply using Carbontracker and some mathematical manipulation is not enough to give the paper the required scientific depth. I therefore recommend the omission of sections 2.8 and 4.2, and to submit the paper to e.g. GMD, which seems a more proper medium to offer this important work to the user community.

Response

We searched ACP for publications describing emission inventories for use in atmospheric research, and found (at least) the following recent publications:

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.

Urbanski, S.P.; Hao, W.M.; Nordgren, B.: The wildland fire emission inventory: western United States emission estimates and an evaluation of uncertainty. Atmos. Chem. Phys., 11, 12973-13000, doi:10.5194/acp-11-12973-2011, 2011

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.

Ohara, T., Akimoto, H., Kurokawa, J., Horii, N., Yamaji, K.,Yan, X., and Hayasaka, T.: An Asian emission inventory of anthropogenic emission sources for the period 1980-2020, Atmos. Chem. Phys., 7, 4419-4444, doi:10.5194/acp-7-4419-2007, 2007.

Inventories are an essential component of atmospheric sciences, as shown for instance by the IGAC/ILEAPS/AIMES GEIA activity dedicated to improve emission inventories. GEIA is a sub activity of IGAC, which coordinates international atmospheric chemistry programs (http://www.igacproject.org/GEIA). Further, the other three reviewers did not point out to any inadequacy of the manuscript for ACP. Therefore, we see no justification for the remark that ACP is the wrong journal.

Regarding the application of using different fossil fuel (FF) emission inventories to solve for biosphere fluxes, we thank the reviewer for reminding us the study by Peylin et al. (2011), which was a first attempt to use two different FF emissions maps for estimating biospheric residual fluxes. We added this reference to the revised manuscript. The Peylin et al. study was limited to Europe, and to our knowledge, there is no published study investigating how uncertainties in FF emissions translate into uncertain biosphere fluxes in inversions. Inversion modelers continue to assume that FF emissions are perfectly known, and solve for biosphere fluxes as a residual. In this respect, implications of different FF emissions on biosphere fluxes is still "new". The following sentence was added on line 12, Page 21225 as: "*For example, Peylin et al. investigated the influence of using different fossil fuel emission inventories on the simulation of CO_2 in the atmosphere in Europe, and pointed out an urgent need to improve the spatially and temporally resolved CO_2 emission inventory (Peylin et al., 2011).*".

The goal of our manuscript is however to describe a new CO_2 emissions inventory to be used by the atmospheric research community, and the CarbonTracker application is a simple illustration. This is clarified in the revised manuscript. Stronger collaborations are needed between the inversion community and by the inventory community to design inversions where inventories uncertainties can be formally accounted for. Once our manuscript published, we will make the emissions data available to the research community, so that this type of new research can be possible. The following sentence was added at the end of Section 4.2 as: "*It should be noted that application of PKU-CO_2 here is only to investigate the influence of sub-national disaggregation method on inversed carbon flux, and a complete application is still ongoing, which will make full use of PKU-CO_2 based on Monte Carlo results and address the uncertainty in the emissions.*".

Reference

Peylin, P., Houweling, S., Krol, M.C., et al.: Importance of fossil fuel emission uncertainties over Europe for CO_2 modeling: model intercomparison. Atmos. Chem. Phys., 11, 6607-6622, doi:10.5194/acp-11-6607-2011, 2011.

Comment 3

Minor: Caption figure 5: VULVAN should read VULCAN.

Response

Sorry for the mistake and it was corrected accordingly.

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MS No.: acp-2012-405
MS Type: Research Article

Reviewer 3 - K.R.G. Gurney, C7856

Comment 1

This is a useful paper on a rapidly evolving sub-portion of carbon cycle research. Better global CO2 emission data products are needed. However, I was troubled by a number of omissions and misunderstandings about some of the input data, methods, and analysis that I believe require correction if this data product is to be published and relied upon by other researchers.

Response

Please see the point-to-point responses to specific comments below.

Comment 2

The first concern revolves around the input data and methods. CARMA is not a scientific-level dataset as it has not undergone any peer-review. My analysis of the dataset shows large and significant biases on the location and emissions estimates. For example, the CARMA dataset provides the center of the city nearest to the reported power plant. Hence, it is unclear how the authors of this paper could reliably check the locations in google earth - many facilities could be located in the vicinity of cities and it is not clear how the correct facility could be identified. This requires more explanation. Datasets that have not undergone peer-review, such as CARMA, must be examined more carefully rather than ingested with little analysis or examination.

Response

We made efforts to check the locations of the power stations provided by CARMA v2.0, which is the best we can get. To do so, all stations in CARMA v2.0 were divided into 10 categories of equal sample sizes based on their annual fuel consumptions. For a stratified sampling, 50 stations (20 in China and 40 in other countries except the U.S.A.) were randomly selected from each category. The exact locations of them were checked on Google Earth by searching the names of the stations and images of power plants (chimneys and cooling towers). Roughly, 3 out of 4 stations selected were found on Google Earth and 1 out of 4 stations could not be identified by visual inspection. As a result, 350 stations with their locations (100 in China and 250 in other countries except the States) were found after 476 stations were searched. These stations were evaluated for the location accuracy in CARMA v2.0 in grid resolution (Figure S1). It will be very difficult for us to check more due to the extremely time-consuming process.

The detailed methodology was added to the caption of Fig. S1 as follows: "***Fig. S1**. Position offsets of randomly selected power stations recorded in the CARMA v2.0. The geographic positions of randomly selected 350 power stations (100 stations in China and 250 stations outside of China and U.S.A.) in the CARMA v2.0 list are checked against the presence of facility locations from visual inspection of Google imagery. The red circles are the true locations identified from Google Earth imagery, which are linked by blue lines to the CARMA v2.0 recorded locations. To do so, all stations in CARMA v2.0 were divided into 10 categories of equal sample sizes based on their annual fuel consumptions. For a stratified sampling, 50 stations (20 in China and 30 in other countries except the U.S.A.) were randomly selected from each category. The exact locations of the power stations were checked on Google Earth by searching the names of the stations and inspecting Google Earth images of power plants (chimneys and cooling towers). Roughly, 3 out of 4 stations selected were found in the Google Earth images, and 1 out of 4 stations could not be identified. As a result, 350 power stations with their locations (100 in China and 250 in other countries except the U.S.A.) were found after 476 stations were searched. The size of each circle is proportional to the emission from each power station. Two satellite images with typical views of power stations found on Google Earth are shown (the reported power stations by CARMA v2.0 are shown as red pentagrams).*"

In addition, the following sentence was added line 6, page 21218 of the revised manuscript: "*It was* *found that 45% (China) and 89.2% (countries other than China and the U.S.A.) of the stations are located in the same grids (0.1°×0.1°) as indicated by CARMA v2.0, and that the remaining 42.0% (China) and 9.2% (countries other than China and U.S.A.) of stations are actually located in grids adjacent to the one listed in CARMA v2.0, indicating that the accuracy of the CARMA v2.0 data is satisfactory for 0.1°×0.1° resolution mapping in countries outside China. The spatial localization errors in China are relatively large. Still, for 87% and 95% of Chinese power stations, the difference between the CARMA v2.0 listed locations and actual locations identified by Google imagery were not more than 2 (20 km) and 3 (30 km) grids, respectively.*"

The sentence (line 12, page 21218) was revised from "*... CARMA is the best global power-stations dataset available up to now...*" to "*... CARMA v2.0 is the best global power-stations dataset available for the year of 2007 ...*".

Comment 3

Furthermore, there is a new CARMA dataset available and the authors should probably be using that data product (with adequate analysis). Since power plants represent such a large portion of global emissions, this is essential.

Response

Thanks for the information. Accordingly, we recognized that CARMA dataset was updated from version 2.0 to version 3.0 in October, 2012. Unfortunately, the new dataset is for years 2004 and 2009. Since our emission inventory was developed for 2007, the CARMA v3.0 could not be used. To make it clear, The sentence (line 12, page 21218) was revised from "*... CARMA is the best global power-stations dataset available up to now...*" to "*... CARMA v2.0 is the best global power-stations dataset available for the year of 2007 ...*".

Comment 4

The authors describe key components of their methodology with inadequate detail. For example, in section 2.3, they refer to "emission proxies following the methods of Gurney et al.". It is not clear what this means. What is an "emission proxy" approach in this context? In the Vulcan effort, the investigators used CO emissions from particular datasets (though not all) and converted CO emissions to fuel. However, the key element is the CO emission factor used. Generic use of emission factor will simply reproduce the error-laden dataset produced by the EPA. One must use the CO emission factors reported by the emitting entities to reproduce fuel consumption. Then, oxidize that to CO2. I am concerned that this was not done. If the authors scaled CO2 with CO, there are a variety of problems with that approach. I think the most useful thing to do, is to carefully describe what exactly was done with CO emissions in those cases where they were used.

Response

It appears that we did not present the result clearly. In fact, we used CO emission data by sector (as listed in Table S2) as an activity proxy to disaggregate fuel consumptions in country (Mexico) and states (the USA) to counties. The sentences on line 5, page 21216 were revised as follows: "*For Group 8 (others), national fuel consumptions of EUCS-36 (IEA,2010a; IEA, 2010b) were disaggregated to 0.5°×0.5° grids using CO emission proxies from the European Monitoring and Evaluation Programme by sector (Table S2) (CEIP, 2011); National fuel consumption of Mexico (IEA, 2010a) and state fuel consumptions of U.S.A. (USEIA, 2008) were allocated to counties using the CO emissions by county as a proxy within the Mexico or U.S.A. states by sector (Table S2) (USEPA, 2006; USEPA, 2011).*" Please refer to the response to the next comments for detail.

Comment 5

Similarly, in the next paragraph, the authors refer to an "inner-interpolation approach was applied following the method developed by Gurney to get the data for 64 fuel sub-types". I do not understand what an "inner-interpolation approach" is? I don't believe the Vulcan effort used "inner-interpolation". Again, a more detailed explanation of these methods is required. The current draft has far too many vague descriptions of critical methods and this leaves the draft potentially misrepresenting the Vulcan approach and leaving the reader with a limited understanding of the methods used and potentially not confident of the outcomes.

Response

The sentences on line 22, page 21216 were revised as follows: "*In processing the sub-national data for these sectors in Group 8 (others), the sub-national fuel data compiled in our local database are listed in Table S2. The fuel sub-types in Group 8 with detailed sub-national consumption data available are marked with a # superscript. For fuel sub-types without detailed data, the shares of these sub-types in each sub-national units (SDUs) were assumed to be equal to the national shares.*".

Table S2 was added to the Supplementary material.

Table S2. Database of sub-national fuel data for the 45 countries (EUCS36, U.S.A., China, Mexico, and C-6). The fuel subtypes in Group 8 (other) with detailed fuel consumption data in the local database are marked with a "#" superscript.

Country	*Fuel sub-types with detailed sub-national data available*
EUCS36	power coal, power oil, industry coal, industry oil, coke production#, aluminum production#, brick production#, petroleum refinery#, residential coal, residential biofuel, waste incineration#, vehicle diesel#, vehicle gasoline#.
China	power coal, industry coal, aluminum production#, brick production#, petroleum refinery#, residential coal, residential straw#, residential firewood#, vehicle diesel#, vehicle gasoline#.
U.S.	power coal, power gas, industry coal, industry oil, industry gas, coke production#, aluminum production#, brick production#, petroleum refinery#, residential coal, residential LPG#, residential gas#, residential biofuel, vehicle diesel#, vehicle gasoline#.
Mexico	power coal, industry coal, residential oil, residential LPG#, residential gas, residential biomass, open solid waste incineration#, vehicle diesel#, vehicle gasoline#.
India	power coal, industry coal, coke production#, residential coal, residential biofuel, residential dung cake#, vehicle diesel#, vehicle gasoline#.
South Africa	power coal, industry coal, coke production#, residential coal, residential biofuel, vehicle diesel#, vehicle gasoline#.
Brazil	power coal, industry coal, coke production#, residential coal, residential biofuel, vehicle diesel#, vehicle gasoline#.
Turkey	power coal, industry coal, coke production#, residential coal, residential biofuel, vehicle diesel#, vehicle gasoline#.
Canada	power coal, industry coal, coke production#, petroleum refinery#, residential coal, residential LPG#, residential gas, vehicle diesel#, vehicle gasoline#, residential biofuel.
Australia	power coal, power oil, power biofuel, industry coal, industry oil, industry gas, industry biofuel, coke production#, residential coal, residential LPG#, residential gas, residential biofuel, vehicle diesel#, vehicle gasoline#.

In addition to the revisions made in response to the specific comments, following revisions were made after the methodology section of the manuscript was double checked.

For aviation/shipping data (Section 2.2), the sentence on line 7, page 21215 was revised into "*For Group 2, global fuel consumptions of aviation (IEA, 2010a; IEA, 2010b) and shipping (Equasis, 2008) were allocated to 0.1°×0.1° using CO emission as a proxy, and CO emissions from aviation (JRC/PBL,2011) and shipping (Wang et al., 2008; Eyers, 2005) were from the literature.*

For power station data (Section 2.2), the following sentences were added to line 7, page 21215: "*National fuel consumptions by other power stations were calculated by subtracting these included in CARMA v2.0 dataset from the national total (IEA,2010a; IEA,2010b) and disaggregated to 0.1°×0.1° using population as a proxy (ORNL,2008).*"

Comment 6

In the section that compares the PKU to ODIAC and Vulcan (section 3.4) the Vulcan data product is misrepresented. The authors state that "area sources were uniformly allocated within counties in the VULCAN. . .". This is incorrect. Vulcan did not evenly distribute emissions into counties but rather distributed according to the area of building square footage and did so into building sub-categories. I urge the authors to read the Vulcan methodology and correct the description provided in this manuscript.

Response

We misunderstood concept of the "U.S. Census tract" before. In the revised version, the VULCAN description in the second paragraph in Section 3.3 was corrected as "*In addition, for area or nonpoint sources, CO_2 emissions were allocated from the counties to the U.S.A. Census tracts according to the area of residential/commercial/industrial building square footage and then distributed to 10km×10km grids via area-based weighting in the VULCAN2.2, while they were disaggregated to 0.1°×0.1° grids using the 0.8km×0.8km population distribution (ORNL,2008) as a proxy within counties in PKU-CO_2.*"

Comment 7

In this section, I would also encourage the authors to compare not to ODIAC but to the Rayner et al. data product that was published in 2010. It is surprising that this paper was not cited in general and more surprising that the comparison was not made to Rayner et al. given that Rayner et al. showed better comparison to Vulcan when compared to ODIAC. This would be a far better test of the PKU results.

Response

The main reason for comparing with ODIAC instead of with the Rayner et al. FFDAS is that both PKU-CO_2 and ODIAC used exact locations for power stations, while emission from power stations were disaggregated to the grids in the FFDAS product (Rayner et al., 2010). Also, we noted that a comparison among ODIAC, FFDAS, one from Brenkert (1998), and VULCAN by Oda and Maksyutov (2011) showed that the correlations between ODIAC and VULCAN were more significant than those between FFDAS and VULCAN at various resolutions in terms of absolute difference and spatial pattern (see Table 3, Oda and Maksyutov, 2011). Beside, for some unknown reason, we could not and still cannot access now access to the FFDAS website (http://ffdas.org/) for a detailed comparison. In the revised version, Rayner et al. paper was cited in the Introduction section (line 16, page 21213): "*To reduce the bias caused by national population-based downscaling, a series of efforts has been made to improve the spatial allocation. For example, Rayner et al. developed a data assimilation method based on the distribution of nightlights and population to produce a global emission field (called FFDAS) at 0.25° resolution, in which the distribution of emission was smoother than that of traditional population-based inventories (Rayner et al., 2010).*"

References

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, http://cdiac.esd.ornl.gov/ndps/ndp058a.html, 1998.

Rayner, P. J., Raupach, M. R., 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.

Oda, T. and Maksyutov, S.: A very high-resolution (1 km×1 km) global fossil fuel CO_2 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.

Comment 8

The comparison to Vulcan requires the identification of the Vulcan version and whether or not the authors used the 10 km or 0.1 degree datasets.

Response

According to the comment, the sentence on line 19, page 21223 was revised as "*The second inventory to which PKU-CO_2 was compared is VULCAN (**version 2.2**), a **0.1°×0.1°** and 1 h resolution CO_2 emission inventory (2002, fossil fuel) established over the U.S.A. (Gurney et al., 2009).*"

Comment 9

Though the comparison to Vulcan shows no overall systematic bias, the scatter in the plot of figure 5 is worth noting. The authors imply that a factor of two difference is "reasonable agreement". I would not agree with that as this seems like a very large amount of disagreement. Would this not support some modification of the uncertainty? Furthermore, I would agree that the differences are due to the traffic issue noted (but as I have said, I disagree with the second reason as a misunderstanding of Vulcan). However, there are a whole variety of other reasons why these data products are different at the gridcell level. In Vulcan, point sources are identified to geocoded locations. That includes most of the industrial sector, 1/2 of the commercial sector, all of cement, all power plants, all airports, etc. Again, I urge the authors to read the Vulcan methodology so it can be correctly characterized in this manuscript.

Response

According to the comment, we studied the Vulcan methodology more carefully. The sentences on line 28, page 21223 was revised as: "*Although no systematic skewness is found, more than 30% of the grid points show a difference larger than a factor of 2 between PKU-CO_2 and VULCAN2.2. These differences are due to the fact that many detailed information used by VULCAN2.2 are not included in PKU-CO_2, such as road GIS data and geocoded locations of point sources of industrial facilities, some commercial sources, and airports. In addition, for area or nonpoint sources, CO_2 emissions were allocated from the counties to the U.S.A. Census tracts according to the area of residential/commercial/industrial building square footage and then distributed to 10km×10km grids via area-based weighting in the VULCAN2.2, while they were* *disaggregated to 0.1°×0.1° grids using the 0.8km×0.8km population distribution (ORNL,2008) as a proxy within counties in PKU-CO_2.* "

In the revised version, we updated the fuel and emission data for vehicles by making use of the global distribution of CO emission from on-road transportation from the EDGAR v4.2 dataset (JRC/PBL,2011). Accordingly, the sentence on line 14, page 21216 was revised as: "*Finally, a population proxy was applied to disaggregate fuel consumptions (the 15197 SDUs for the 45 countries and remaining 178 countries) to 0.1°×0.1° grids (ORNL, 2008) except for on-road gasoline and diesel vehicles, for which 0.1°×0.1° CO emission from road transportation in EDGARv4.2 (JRC/PBL,2011) was used as a proxy.*"

References

European Commission, Joint Research Centre (JRC)/Netherlands Environmental Assessment Agency (PBL). Emission Database for Global Atmospheric Research (EDGAR), release version 4.2. http://edgar.jrc.ec.europa.eu, 2011.

Comment 10

Finally, a difference plot in figure 5 would be much more illuminating. The side-by-side emissions reveal little and don't show what is important – the differences.

Response

A difference plot was added to Fig. 5 as follows:

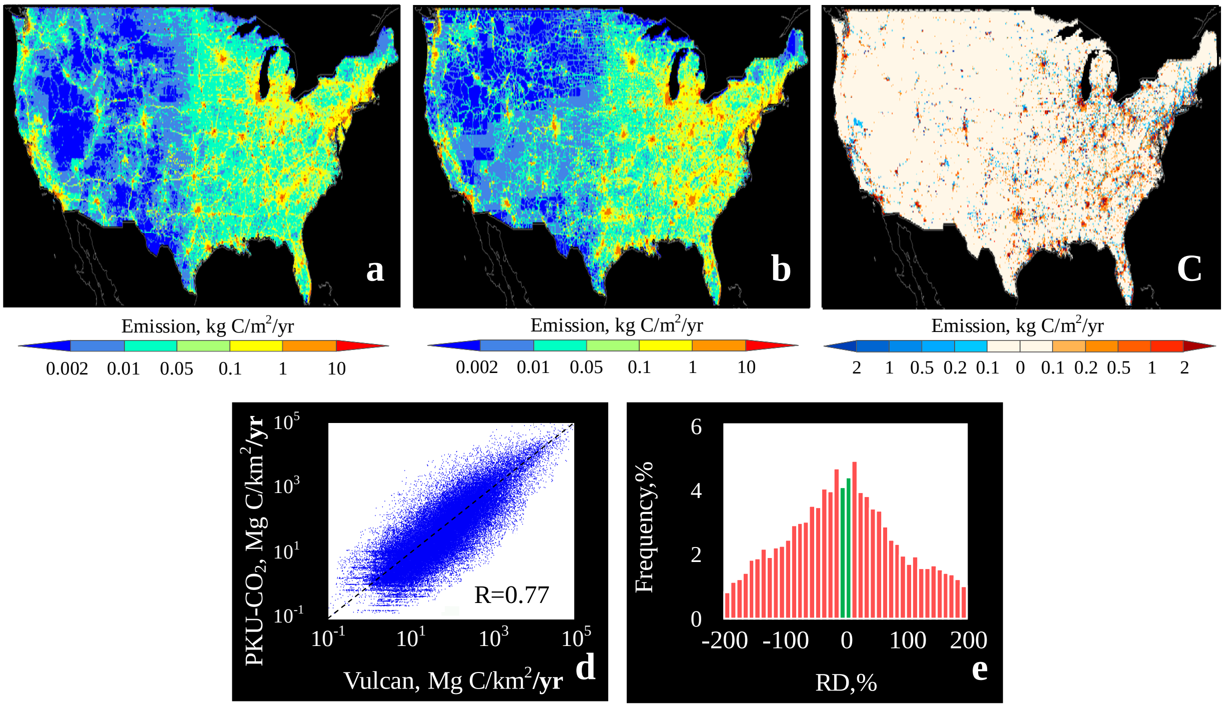

Fig. 5. Comparison between the VULCAN2.2 (a very detailed fossil fuel CO_2 process-based emission inventory model, only available over the U.S.A. territory, normalized for individual counties to correct for the difference between 2002 and 2007) and the PKU-CO_2 inventory (this study) created at the resolution of 0.1° over the globe. (a) VULCAN2.2 emissions corrected to year 2007; (b) the PKU-CO_2 inventory established for year 2007; (c) the difference plot between PKU-CO_2 and corrected VULCAN2.2. (d) log-scaled scatter plot of grid-point emissions (84166 grid-points) in PKU-CO_2 and corrected VULCAN2.2; (e) Frequency distribution of relative differences (RD) of grid-point emissions between PKU-CO_2 and corrected VULCAN2.2. We do not expect PKU-CO_2 to be more realistic than the VULCAN2.2 inventory, but this comparison is shown to illustrate how PKU-CO_2 approaches VULCAN2.2 best product over a region where the comparison is possible.

Comment 11

In section 2.4, the authors refer to "combustion rates" and provide a series of numerical values. Are they meaning oxidation rates? It is unclear what is meant here. English grammar requires improvement throughout the paper. The tenses are often mixed, plural is mixed with non, etc.

Response

"*combustion rates*" was revised to "*oxidation rates*", accordingly. We double checked the grammar in the manuscript under the help of two native English speakers.

Comment 12

I would encourage this journal to require that the resulting data product and the input datasets be made publicly available as a condition of publication. This is crucial for other investigators to reproduce and analyze these results. If the journal does not require this, I would urge the authors to do so independently.

Response

Yes, we will make our data product available for other to use.

Comment 13

Citations: No mention is made of the work by Marland et al., which is key to the context of any paper on the this topic, in my opinion.

Response

We did heavily cite one paper from Marland's group (Andres et al.,1996). Two more references of Marland et al. were included in the revised version accordingly. The sentence on line 25, page 21212 was revised as: "*To quantitatively characterize the climate forcing and health impacts, global emission inventories of CO_2 and air pollutants were developed years ago (Marland et al., 1985; Andres et al., 1996; Penner et al., 1993).*" The sentence on line 20, page 21218 was revised as: "*A CV of 10% was adopted for all other fuel consumptions, with a uniform distribution (Ciais et al., 2010; Marland et al., 2008).*"

References

Marland, G.: Uncertainties in Accounting for CO_2 From Fossil Fuels. J. of Indust. Ecol., 12, 136-139, doi:10.1111/j.1530-9290. 2008.00014.x, 2008.

Marland, G.; Rotty, R. M.; Treat, N. L. CO_2 from fossil fuel burning: global distribution of emissions. Tellus 1985, 37B, 243-258.

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MS No.: acp-2012-405
MS Type: Research Article

Reviewer 4 - Anonymous Referee, C8164

Comment 1

I recommend rejecting the manuscript in the present from. It potentially might become publishable after substantial revision, which cannot be achieved in few weeks. The manuscript describes of global spatially highly-resolved inventories of fuel burn and CO_2 emissions, which can eventually become a highly valuable source of information for climate-chemistry modeling, satellite date evaluation and policy making.

Response
Please refer to the point-to-point responses to detailed comments.

Comment 2

However, the present approach pretends a spatial accuracy, which mostly appears to be an artefact of the applied downscaling method (see also below), lacking a sound evaluation. Without clear caveats about the methods, this may lead to false interpretation of the results and potentially to wrong political decisions.

Response
The basic hypothesis tested in this study is that **per-capita fuel consumptions are not evenly distributed within a large country, especially for a large developing country**. Therefore, a sub-national disaggregation method using ACTUAL CENSUS of sub-national fuel data is always superior to a national disaggregation method using national fuel data. This hypothesis was tested directly in our manuscript by comparing per-capita fuel consumption data in different provinces or counties in a country. For example, per capita fuel consumptions in various provinces in China range from 0.03 to 0.12 TJ/cap (4 times difference) and per capita fuel consumptions in various counties in Inner Mongolia, China range from 0.018 to 1.38 TJ/cap (77 times difference). These large differences demonstrate without ambiguity that a large spatial bias is induced by disaggregating national fuel consumption to grid points, when using national population as a proxy. The global spatial distribution of the difference is presented in Fig 2 for 45 countries where we have compiled sub-national data. The sub-national fuel consumption and population data are NEW DATA and not artifact, as suggested by the reviewer.
In fact, we show that improvement obtained by replacing national fuel data disaggregation with sub-national fuel data disaggregation is similar to that obtained by replacing global disaggregation (only use global total fuel consumption and global population distribution) with national disaggregation.
The sub-national fuel consumptions data for the 45 countries cover most of the 64 fuel types in our study (Groups 3 and Group 8 in the paper, approximately 70% of the total global CO_2 emission including power plants and natural gas flaring in 2007). If wild fire is included, the contributions reached 90% of the total. There are several specific sectors, for which the sub-national or high-resolution data are not available. Cement production (3.3%) and aviation (0.8%) happen to be among them. For these sectors, we had to rely on the available database and convert them to the same resolution as other sectors, which can surely cause artifact. The improvement on these sectors can be made when more reliable data become available in the future. According to the comment, the following paragraph was added in Section 3.2 in the revised version to

clarify these limitations:

"*This study focused on testing the hypothesis that per-capita fuel consumptions distribute unevenly within individual countries and developing a sub-national disaggregation method using sub-national fuel consumption data for establishing a high-resolution global fuel consumption and CO_2 emission inventory. The main constrains of the inventory include geo-locations of power plants from CARMA v2.0 are not always accurate for countries like China, the sub-national fuel consumption data are not available for all countries, especially large developing countries such as Indonesia; and for some sources including aviation, dung cake, and cement production, relatively high disaggregation uncertainty is expected because no detailed spatial data are available. For example, the aviation data are based on representative flight movement inventories and cannot cover all flights. Spatial allocation of cement production are based on the distribution of industrial coal consumption as a proxy, rather than using a cement plant map like EDGAR v4.2 (JRC/PBL,2011).*"

Comment 3

l 82-84: The aviation data used as input are probably from EDGAR. I.e. they are based of lower resolution data originating either from great circle routes or from few days of actual flights. In the light of the variability of flight routes due to weather and heavy traffic is far beyond the resolution of EDGAR. Therefore downscaling these data to 0.1°x0.1° is only a mathematical exercise. The result pretends accuracy, which only is an artefact of the method without any reliability. Furthermore the present manuscript appears to ignore the large uncertainty with respect to different aviation emission inventories. (The cases of aviation and cement production only serve as examples of the weakness of the manuscript.)

Response

Yes, the aviation data are from EDGAR v4.2. To make it clear, the sentence on **line 7, page 21215** was revised as "*For Group 2 (aviation/shipping), global fuel consumptions of aviation (IEA, 2010a; IEA, 2010b) and shipping (Equasis, 2008) were allocated to 0.1°×0.1° using CO emissions as a proxy; CO emissions from aviation (JRC/PBL,2011) and shipping (Wang et al., 2008; Eyers, 2005) were taken from the literature.*" The uncertainty for aviation data was emphasized in the revised version (please refer to the response to **Comment 2**).

In addition, in the revised version, we updated the fuel and emission data for vehicles by making use of the global distribution of CO emission from on-road transportation from the EDGARv4.2 dataset (JRC/PBL,2011). Accordingly, the sentence on line 14, page 21216 was revised as: "*Finally, a population proxy was applied to disaggregate fuel consumptions (the 15197 SDUs for the 45 countries and remaining 178 countries) to 0.1°×0.1° grids (ORNL, 2008) except for on-road gasoline and diesel vehicles, for which 0.1°×0.1° CO emission from road transportation in EDGARv4.2 (JRC/PBL,2011) was used as a proxy.*"

References

European Commission, Joint Research Centre (JRC)/Netherlands Environmental Assessment Agency (PBL). Emission Database for Global Atmospheric Research (EDGAR), release version 4.2. http://edgar.jrc.ec.europa.eu, 2011.

Comment 4

133-136: CO2 emissions from cement production were disaggregated using industrial coal consumption. To my knowledge, cement production is much more localised than industrial coal consumption, i.e. here the method makes wrong distributions. (The cases of aviation and cement production only serve as examples of the weakness of the manuscript.)

Response

We agree with the reviewer that cement production does not necessarily overlap with that of industrial coal consumption, but without access to the information on the geo-spatial distribution of cement factories worldwide, we had to assumed industrial coal consumption to be a better proxy of cement production emissions than population such as used by others (Andres et al., 1996).

Compared with many other sources (JRC/PBL,2011), there are relatively high uncertainty in disaggregation of emissions from national emission by cement production. Hopefully, more data can be available in the future which can be used to reduce the uncertainty. Please also refer to the response to **Comment 2**).

References

Andres, R. J., Marland, G., Fung, I. E., and Matthews, E. A.: 0.1°´0.1° distribution of carbon dioxide emissions from fossil fuel consumption and cement manufacture, 1950–1990, Global Biogeochem. Cy., 10, 419-429, 1996.

European Commission, Joint Research Centre (JRC)/Netherlands Environmental Assessment Agency (PBL). Emission Database for Global Atmospheric Research (EDGAR), release version 4.2. http://edgar.jrc.ec.europa.eu, 2011.

Comment 5

Provide important information such as the sectorial emissions in line 186-188, l 191 ff in Table. That will increase the readability of the manuscript.

Response

These information were included in the Table S5 in the previous version, which was moved to the main text according to **Comment** 8.

Comment 6

301 ff: PKU-CO2 only helps to reduce uncertainty in atmospheric modeling, if PKU-CO2 itself has a high reliability, which the manuscript lacks to prove.

Response

PKU-CO_2 has a better reliability because it is based on subnational data. We do not know the true value of emissions, so comparison against truth is impossible for all the existing inventories.

Still, the results of using detailed sub-national data should be better than those using only national data logically. Base on the sub-national fuel consumption data collected in this study, per capita fuel consumption within a country are far from evenly distributed. For example, provincial per capita fuel consumptions in China varied from 0.03 to 0.12 TJ/cap and county per capita fuel consumptions in Inner Mongolia, China varied from 0.018 to 1.38 TJ/cap. These TURE data well support our assumption and Fig. 2 presents exactly the improvement of the PKU-CO_2 on correcting spatial bias due to uneven distribution of per capita fuel consumptions. In fact, the statement saying that the sub-national disaggregation method using sub-national fuel data is better than national disaggregation method using national fuel data is actually similar to the statement saying that national disaggregation method using national data is better than disaggregation method using global population and global fuel consumption directly, which we think is well accepted. Of course, the results should be proved by the results of modeling and monitoring. For this purpose, we will welcome others to use and evaluate the data product after it is published.

To demonstrate the uncertainty reduction using the sub-national data, both the PKU-CO_2 and NAT-CO_2 were compared with the VULCAN inventory over the U.S.A., which is more realistic since detailed activity data were used. The improvement of PKU-CO_2 over NAT-CO_2 is well demonstrated. The following sentences were added at the end of Section 3.4: "*In addition, the improvement of the sub-national disaggregation method was also tested by comparing both PKU-CO_2 and NAT-CO_2 with the VULCAN2.2 inventory at various resolutions from 0.1° to 4°. The average absolute values of RD between PKU-CO_2 and VULCAN2.2 were much smaller than those between the NAT-CO_2 and VULCAN2.2 (Table S5), indicating a reduction of spatial bias over the national disaggregation method.*"

Table S5 was added to the Supplementary material as:

Table S5. Comparison of the PKU-CO_2 and NAT-CO_2 inventory with the VULCAN2.2 inventory (Gurney et al,

2009) over the U.S.A.. The comparisons are conducted by calculating the average absolute relative differences (RD).

Resolution	*Average absolute RD*	
	NAT-CO_2	*PKU-CO_2*
0.1°	101.0%	74.1%
0.5°	80.4%	54.2%
1°	66.0%	48.6%
2°	55.5%	42.1%
3°	54.2%	32.2%
4°	54.0%	25.7%

Comment 7

Provide a caveat section, which clearly shows the limitations of your method.

Response

A paragraph was added accordingly and please refer to the response to **Comment 2** for the detailed revision.

Comment 8

Transfer important table from the supplementary material to the main text.

Response

According to the comment, Table S1, Table S3, and Table S5 were moved from the supplementary material to the main text.

Comment 9

Figs 2 and 4 show a weakness of the method. I cannot belief that, for instance, the emissions pattern significantly change at the border between the USA and Canada, or between the European and Asian parts of Russia. These pattern can only be artefacts of the methods applied.

Response

The reviewer made an error in interpreting this figure as an artifact of PKU-CO_2. In fact, Fig 2 is a difference plot between sub-national disaggregation (this study) and the LESS REALISTIC national disaggregation method (commonly used by inventory studies), rather than a difference "**emission pattern**". Therefore, national borders discontinuities (between the countries with and without sub-national data available) in Fig 2 illustrate the IMPROVEMENT of using the sub-national disaggregation method over a national disaggregation method. The change at the border between the USA and Canada (and other borders) was due to the difference in data resolution (county data for the USA and provincial data for Canada). It suggests that the result can be further improved if higher solution data are available for Canada (e.g. counties) and other countries. Similarly, high-resolution data is available for the European Russia, but not for the Asian Russia. We can say that the lack of more detailed fuel data than average values for large provinces in Canada, Brazil, Russia is a limitation of our approach, which is common to all other approaches until high resolution data become available for all countries in the world, which unfortunately is not the case.

To make the presentation more clear, a sentence was added to the caption of **Fig 2** (**Fig. 7** as well) as follows "*The RD could not be calculated for the countries where sub-national data were not available or not reported, and these areas are marked in black.*"

For Fig 4, we can not find significantly changes across country boarders.

Comment 10

It would be helpful, if the authors provide a web address where potential users can download the data, once the (substantially improved) manuscript is published.

Response

We are planning to make the data product available for other to use after the manuscript is published.

Comment 11

How do the present results compare with the UNFCCC data?

Response

We did not compared our results with the UNFCCC data in our study. According to the comment, we tried to do the comparison for several countries and the results are as follows: PKU-CO_2 vs. UNFCCC (Tg CO_2/a): 5940/5937 for USA, 533/547 for UK, 908/1090 for Germany, and 1700/1579 for Russia. Since data for China is not included in the UNFCCC and these are only total emissions based on total fuel consumption data, which is not the focus (spatial distribution) of this study, these comparison are not added to the manuscript.

Comment 12

Provide a list of abbreviations.

Response

A list of all abbreviations as follows was added at the end of the paper accordingly.

CO_2: carbon dioxide
SDM: sub-national disaggregation method
EF: emission factor
F_{cap}: per-capita fuel consumption
E_{cap}: per-capita CO_2 emission
GOSAT: Japanese Greenhouse gases Observing SATellite Project
PKU: Peking University
PKU-FUEL: Peking University Fuel Inventories
PKU-CO_2: Peking University CO_2 Inventories
ECS-36: the 36 European countries with sub-national data
SDU: Sub-nationally Disaggregated Unit
Nat-CO2: a mock-up inventory generated basing on the national fuel data and disaggregation
CO: carbon monoxide
NOx: nitrogen oxide
CARMA: Carbon Monitoring for Action
CV: coefficients of variation
RD: relative difference
R_{90}: 95th minus 5th percentile range)
M: median
R_{90}/M: the ratio of R_{90} to median
ODIAC: Open source Data Inventory of Anthropogenic CO_2 emission
IEA: International Energy Agency
EDGAR: The Emissions Database for Global Atmospheric Research
MAV: More Accurate Value

Comment 13

l 20: The SI unit for year is "a" not "yr".

Response

Based on the official definitions of SI units, “yr” or “y” are recommended. Please see the following quotation: “*There is no official symbol for the year, but y, yr, and a are probably the most common; note that “a” conflicts with the symbol for the are*.”

http://lamar.colostate.edu/~hillger/unit-definitions.html#year

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Comment 14

56: Do not use "EC-36" for the European countries. "EC" normally means "European Commission".

Response

“EC-36” was revised as “36 European countries with sub-national data (EUCS-36)”.

Comment 15

57: Use "USA" or "U.S.A" as abbreviation for the United States of America. There are many United States in the world. (US is slang used in the USA from their view point of the world.)

Response

Revised accordingly in the revised version.

Comment 16

80-96: Provide the name behind the Groups, e.g., "Group 1 (wildfire). The reader is not as familiar with your nomenclature as the authors are.

Response

“*Group XX*” was used as “*Group XX (description)*” in the revised version accordingly.

Comment 17

l 83 and many later places: I guess it should read "CO2 emissions".

Response

It is “*CO emission*”. Here, we used the spatial distribution of CO emissions as a proxy to disaggregate the fuel consumptions to individual grids. The CO_2 emissions in the PKU-CO_2 was calculated separately according to the fuel data and CO_2 emission factors.

Comment 18

139: What does the "(4)" at the end of the line mean?

Response

It was a reference which was marked by number in our drafted manuscript. It was revised as (*CARMA,2010*) in the revised version.

Comment 19

References: Sort the reference with the names used for citing in the text, e.g., "JRC".

Response

Revised accordingly.

Comment 20

Fig 1b. Explain the high values of per capita CO2 emissions in the Western USA or Finland.

Response

To explain it, the following sentence was added on **line 3, page 21221** as follows “*In **Fig. 1b**, E_{cap} was high in the Western U.S.A. because of relatively high fuel consumptions for transportation in states with low population densities Wyoming, North Dakota and Texas (USEIA,2008) . For Alaska and northern Europe, more fuel was consumed for heating in winter.*”

Reference

US Energy Information Administration (USEIA): State Energy Data, available at: http://www. eia.gov/, 2008.

Comment 21

Table S2: I do not think Poland considers itself being a developing country.

Response

Poland was re-categorized as developing country in the revised version accordingly.