**Atmospheric
Chemistry
and Physics
Discussions**

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Interactive comment on "Eddy covariance measurements of CO_2 and energy fluxes in the city of Beijing" *by* H. Z. Liu et al.

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Replies on the comments by Anonymous Referee #3

Referee #3: MAJOR COMMENTS This paper presents an interesting and valuable long-term dataset of primarily carbon dioxide fluxes from a unique urban surface (dense residential high-rise) which is not yet discussed in the literature. Unique is the discussion and control of emissions during the 2008 Olympic Games but as Reviewer #1 has already mentioned, the same data is published in Song and Wang, Atmos. Research, 106, p. 139-149. I am wondering to what extent the analysis repeated here adds to this aspect. Despite the quality of the measurements and the long-term dataset is excellent, the analysis and discussion must be improved in the following points, before the paper can be accepted.

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Reply: We would like to thank the referee for thorough comments on this manuscript. In the revised manuscript, we have corrected the paper according to the comments point by point. The detailed responses are in the following.

1) The incorporation of the 'energy fluxes' is not satisfying. The authors essentially present and discuss turbulent fluxes of sensible heat and latent heat only, and they omit the driving input, net all-wave radiation and also storage heat fluxes and anthropogenic heat fluxes that are all part of the urban energy balance. The title refers to 'energy fluxes' (which includes radiative, storage, and anthropogenic heat fluxes), but essentially only turbulent sensible and latent heat flux densities are reported. I am wondering if the manuscript should contain the turbulent fluxes of sensible heat and latent heat at all. The paper is almost entirely about CO_2 fluxes, not sure if the energy balance sections are necessary.

Reply: We have removed 'energy fluxes' from the title in the revised manuscript. This manuscript mainly focuses on CO_2 flux in Beijing. The result of energy fluxes are only used to distinguish the dry and wet seasons in this manuscript.

2) Calculations of fluxes: (2.1) The data processing has been documented quite carefully and seems to follow a rigorous protocol. However it is quite likely that given the height (47m) and the relative high frequency of stable conditions, the EC level decouples from the surface. As a consequence, the timing of fluxes could be incorrect because authors have not accounted for any storage correction (concentration change below measurement volume, see Feigenwinter et al., 2012 regarding the importance of this term -> "Eddy Covariance - A Practical Guide to Measurement and Data Analysis" - Chapter 16 on urban EC measurements). There is no justification given why a storage correction has not been incorporated or a discussion of what are the implications of omitting this correction. (2.2) The u* threshold discussion should be more prominent and supported by data (see also other reviews) - the high frequency of stable conditions suggests that this could be relevant. Omitting any u* correction should be justified and discussed in more detail in the article.

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Reply: We are sorry that we didn't measure the profile of CO2 concentration in the canopy until now. On the other hand we think that the storage term could be ignored in the calculation of Fc due to anthropogenic heat emissions in the boundary layer at night (the atmosphere is usually at the near neutral or little stable stratifications during the night at the Beijing megacity). For most of the studies over urban areas as we know, such as Helfter et al.(2011), Pawlak et al.(2011) etc., the storage term is not considered until now, while it is we need to consider for the next step on the urban carbon flux. Some errors were found in the figures of stability statistics which omitted d (zero-plane displacement length) in the original revised manuscript. The errors were corrected in the new revised manuscript. The categories of stratification were also redefined. The fraction of strongly stable stratifications was relatively small at night. The u* filtering approach is problematic in urban areas due to anthropogenic heat emissions, releases of storage heat to the boundary layer at night. For our site, the frequency of the cases with u* less than 0.2 m sˆ-1 at night is 31.2%, indicating that u* are large for most of the time at night in this urban environment. Therefore, u* correction is omitted in the present study since that the atmosphere is usually at the near neutral or little stable stratifications during the night at the Beijing megacity.

3) Filtering: (3.1) The MDV approach (l. 203) is not appropriate / justified if the adjacent days are a weekend and the day to be filled is a weekday or vice versa. It could be assumed that the emission patterns and the magnitudes on weekdays and weekends are quite different (and authors demonstrate this). (3.2) The model by Hui et al. (2003) has been developed for non-urban surfaces and it is highly questionable if the controls of emissions in the current urban ecosystem are indeed air temperature (maybe for space heating requirements), humidity (why?), wind direction (OK). But what about day-of-week?, time of day? traffic load?. The gap filling section needs a more careful description and discussion. (3.3) The reader should be convinced that the gap filling works properly, for example - artificially (randomly) removing data and then quantifying how well the gap-fill model performs relative to the actual (artificially removed) dataset.

Reply: We have distinguished weekend and weekday when using MDV approach. If the gaps occurred in the weekend, the gaps were not filled by MDV, but they were filled by the MI (multiple imputation) method. There are no standard gap filling methods for the Fc gaps over urban surfaces until now. Considering the source of CO2 are unstable in Beijing (the mobile cars are always increasing in the cities of this developing country), the neural network method is not suitable to be applied. We finally chose the MI method for it considers most of the relative meteorological factors. The method certainly has some errors, but there is no more suitable method for this urban area until now. The time of day in weekday and weekend is considered when filling the gaps of Fc. In the gap filling procedure, we not only fill the Fc gaps but also the gaps of sensible heat flux and latent heat flux. The humidity factor was considered when filling the gaps of latent heat flux. In order to give clearer information, the sentence was corrected. Only the factors considered in the filling Fc gaps are given in the revised manuscript. Besides, some obvious spikes, which the spike detection procedure failed to identify, were removed artificially.

4) The authors should provide more spatial and temporal information about the controls on emissions - The quality of the manuscript's discussion is lessened because a number of conclusions about the controls on Fc are not proven but rather just speculated - including heating requirements, traffic, behavioral patterns, cooking etc. Many of the speculations listed could be relatively easily verified using appropriate data (heating degree days, a survey of heating systems, population density around tower, traffic counts on highways). The paper unfortunately lacks a rigorous discussion of the properties and metabolism of the surrounding urban area that control fluxes. I agree with both previous reviewers that this aspect should be improved.

Reply: We are sorry that the survey data are difficult to be obtained or doesn't exist at all partially in the Beijing city until now, where the economies and the city's infrastructure construction are at the rapid development phases. Besides, some of the survey projects for basic dataset have not been supported by the government or any other

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foundation. With little funding, some surveys are difficult to be made. The data such as heating degree days, traffic counts around the tower are not available until now. Therefore, the discussions of these data are not considered in the present study.

5) Units of CO2 flux densities - Generally, all units of the carbon-dioxide flux densities that are expressed in mass must include if the mass refers to CO2 or C only (Example: l. 245: mg mˆ-2 sˆ-1 must become mg C mˆ-2 sˆ-1 OR mg CO2 mˆ-2 sˆ-1 (whatever authors have calculated). An alternative would be to provide fluxes in μmol mˆ-2 sˆ-1 (and on l. 270 and 273 ff μmol mˆ-2 sˆ-1 is mostly used, but on line 274 it is again mg CO2 OR C? mˆ-2 sˆ-1). For the annual totals, I suggest to stay with kg C mˆ-2 yˆ-1 (e.g. l. 357) because that is the usual unit in the literature.

Reply: Corrected. The units of Fc are all changed to μmol mˆ-2 sˆ-1. The units of total annual Fc are all changed to kg C mˆ-2 yˆ-1.

MINOR AND EDITORIAL COMMENTS I agree with all the excellent minor and editorial comments made by anonymous reviewer 2 (RC C1781: 'Review', Anonymous Referee #1, 23 Apr 2012 - as annotations in the pdf). In addition to those: Title - The manuscript does not quantify the total emissions from the city of Beijing, but rather quantifies fluxes from a specific neighborhood. The title should be modified accordingly. (line numbers refer to the line numbers on the print layout)

Reply: The title has been changed.

l. 11 (Abstract)- "Long-term measurement of carbon dioxide flux (Fc) AND THE EN-ERGY BALANCE...."

Reply: Corrected.

l. 12 (Abstract) - "in the Beijing megacity" -> "in Beijing, China". The abstract should make clear that fluxes are from a neighborhood and not the entire city.

Reply: Corrected.

l. 14 ff. (Abstract): The energy balance partitioning between latent and sensible heat flux is summarized for summer and spring, but no indication of fall and winter is given.

Reply: Corrected. Winter and autumn are two transition periods of the dominating fluxes.

l. 17 - 19 (Abstract): Sentence requires editing.

Reply: Corrected.

l. 21 (Abstract) - "automobile traffic" - What supports the fact that only automobiles are relevant and not busses, freight trucks and motorcycles? Reply: "automobile" was deleted. The traffic here refers to vehicles, such as cars, busses, trucks etc.

l. 26/27 (Abstract) - "Total annual average CO2 emissions were estimated... " -> "Total annual average CO2 emissions in the source area of the tower were estimated... "

Reply: Corrected.

l 37 ff. - "Emissions of greenhouse gases (GHG)". Even without a city there could be possibly emissions of GHG. Authors should say enhances emission / emissions associated with the combustion of fossil fuels.

Reply: Corrected.

l. 42 - 2005 - > update to 2006 - 2009 period.

Reply: Corrected.

l. 43 – Change C to K (for differences the SI system requires the use of K)

Reply: Corrected.

l. 51 - complex morphological nature -> be more encompassing, it is the "complex land cover, morphology and metabolism of the urban ECOSYSTEM" (I propose to exchange "Urban Landscape" by "Urban Ecosystem"). In addition it is also the arrangement of emission sources and sinks that makes measurements challenging.

Reply: Corrected.

l. 136 - "surface cover sectors". The terms refer to the Stewart and Oke LCZ scheme and as such authors should rather say four different "Local Climate Zones"

Reply: Corrected.

l. 152 -> 'Constant flux layer" -> more common is the term "Inertial sublayer" see Rotach 1999 for example.

Reply: Corrected.

l. 154 -> to assess flow distortion, in addition to the length of the boom, the structure of the tower (open, filled) and the tower's diameter should be given.

Reply: Corrected.

l. 163 - 165 - Anemometers are not further used in this manuscript, so why list them?

Reply: Corrected. Only the 47m level is listed.

l. 200 - "approximately 70%". Other losses are given with 1 significant digit, why not here?

Reply: Corrected.

l. 215 - 217 - "... monsoon ..." -> not needed in the context of this manuscript. Rather define which months are dry season and which ones are wet seasons (see below).

Reply: The sentence is deleted. The wet season lasts from May to October, while the other time of the year is the dry season.

l. 234 - "Le" should be "lambda E" where "lambda" is a greek lambda symbol. No space in-between. Applies to all following instances of "Le".

Reply: Corrected.

l. 237 - which months are referred to as "dry season"? Which months are the rainy

season?

Reply: The wet season is from May to October, while the other time of the year is the dry season.

l. 248 - Domestic heating - what is the dominant heating system (natural gas and oil released locally, or power / steam that is associated with CO_2 emissions outside the study area?

Reply: The natural gas is mainly used for domestic heating in Beijing from 2006.

l. 283 - What justifies that home cooking is the source of CO_2 and not the start of the heating systems as radiation and air temperature decrease towards the evening?

Reply: The home cooking is usually at 18:00-20:00, while the factory for the heating systems around the tower area is far from our measurement site in winter.

l. 321 - I understand that the emission reduction of CO_2 was not the motivation factory closures and traffic restrictions, but rather a reduction of air pollutants. So the sentence "where effectively reduced" is not appropriate, authors could maybe say "as a side effect".

Reply:The analysis of Fc during the Olympic Games has been published in the paper by Song and Wang (2012). This part has been deleted in this manuscript.

l 337 - I expect there must be some traffic counts available in Beijing to support and quantify the "much lower" traffic on cold winter nights. (Same applies to summer l. 339-> quantify traffic load differences).

Reply: We have collected the data of the total amount of traffic for each year. The traffic numbers during the Olympic Games are found in the paper by Pan et al. (Characteristics of urban black carbon concentration around 2008 Beijing Olympic Games, 2010, in Chinese). But unfortunately, the detailed traffic data for other times in the study period are unavailable until now.

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l. 368 - not only "annual scale", but also "inter-annual variation".

Reply: Corrected.

l. 372 - "Is partially moderated by urban vegetation?- this statement is not supported in the results. What is the evidence that there is uptake by vegetation?

Reply: The measured Fc values in the west were much lower due to CO_2 uptake by vegetation in the park (Section 4.5).

l. 378 - by 2.28 μmol mˆ-2 sˆ-2 -> Also provide the relative reduction compared to other years (keep the absolute reduction)? Could this be used to infer the overall contribution of the traffic?

Reply: The analysis of Fc during the Olympic Games has been published in the paper by Song and Wang (2012). This part has been deleted in this manuscript.

l. 381 - It is unclear how the values obtained in this study can be used "for urban development and help to shape policies" and I disagree that they are directly useful. The results and findings could be used to validate emission models, but this would require a spatial analysis. Therefore, I suggest to remove this part of the conclusions.

Reply: Corrected. The sentence has been changed to "The results presented here can provide valuable information for validating emission inventories used for air quality and emission models."

Figure 1 - requires "%" unit added to 50 and 90. Labels for where the Beijing-Tibet expressway is, and the part that is referred to in the text would help. Is the Korman and Meixner Source Area Model applicable in this morphology?, and what are the inputs?-> should be discussed in the manuscript.

Reply: Corrected. More discussion of the footprint was added to the manuscript. There are no operational footprint models for urban surfaces that fully account for topography and spatial variations of the buildings. In this manuscript, we use an analytical footprint

model to assess the source area of Fc. Inputs of the model are u, u*, L, sigma v, wd etc.

Figure 9 - "Olympic GameS"(add "s" and is 2006 - 2009 including 2008? or 2006, 2007 and 2009?

Reply: The analysis of Fc during the Olympic Games has been published in the paper by Song and Wang (2012). This part has been deleted in this manuscript.

Thanks again for your valuable comments and suggestions.

Interactive comment on Atmos. Chem. Phys. Discuss., 12, 7677, 2012.