

Interactive comment on “Diurnal, synoptic and seasonal variability of atmospheric CO₂ in the Paris megacity area” by Irène Xueref-Remy et al.

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Received and published: 24 July 2017

Atmos. Chem. Phys. Discuss., doi:10.5194/acp-2016-218-RC1, 2016 © Author(s)
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Answer to Referee 1 (Jocelyn Turnbull) by Irène Xueref-Remy et al

to “Interactive comment on “Diurnal, synoptic and seasonal variability of atmospheric CO₂ in the Paris megacity area” by Irène Xueref-Remy et al. “

REF 1 : This paper describes a year-long series of in situ CO₂ measurements from sites in and around Paris. The paper focuses on how and why the CO₂ signals vary: the proximity to the city; height of the inlet above ground; variability in emission sources; wind direction and speed. They demonstrate that in many wind regimes, emissions

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from upwind sources can contribute as much or more CO₂ than local Paris emissions. They show that urban CO₂ variability is complex, implying that a strong understanding of these factors and the particular sampling network is needed to infer the emission flux from such measurements. Of particular note is that the Eiffel Tower sampling site is challenging to interpret since the inlet height is only sometimes within the boundary layer. This is a very nice, detailed examination of urban CO₂ source variability that will be useful for the existing and upcoming urban greenhouse gas researchers. This research area is still in its infancy, and this study gives a very good demonstration of how urban sampling networks should be designed and the types of problems that can be encountered. This paper is entirely appropriate for publication in ACP. I see no major issues with the paper, and recommend minor revisions for clarity and language usage.

Authors : The authors thank very much Jocelyn Turnbull for her careful reading and for her constructive feedbacks. We answer to each point that she mentioned hereafter. The first author apologizes for the time that it took us to send our reply, due to her particular situation as she recently left LSCE to move to another institute in the south-east of France.

REF 1 : Specific comments: The authors should edit the full paper for correct English grammar. I point out some specific words in further comments, but there are many other cases where the grammar is comprehensible but incorrect.

Authors : We thank Referee 1 for this comment and we will edit the full paper for correct English grammar.

REF 1 : Abstract page 1 line 31. “elevated” is used here and in other places through the paper to mean “sites where the inlet is well above ground level”. This is confusing though, because “elevated” is also commonly used to mean “the CO₂ is higher than background”. Perhaps “two sites with inlets high above ground level”?

Authors : The correction will appear according to Ref.1’s suggestion.

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REF 1 : Introduction pg 3 line 3 (and several other times in the paper). “conurbation” is not commonly used in English – I am a native speaker and had to look up the meaning. Perhaps “metropolitan area” would be a better choice.

Authors : The correction will appear according to Ref.1’s suggestion.

REF 1 : Pg 5 ln 3-12. Are there any large point sources in the metropolitan area? You mention some in the next section, but it would be helpful to first give them in this section.

Authors : Yes there are large point sources, mostly from the industrial sectors. According to Ref.1’s suggestion, we will add some information about these sources in section 2.1.

REF 1 : Pg 6 lines 13-31. Are there any emissions directly from the buildings you are sampling on top of?

Authors : The sites were carefully chosen so that none of them emits in a way that could directly contaminate the sampling inlet. We will add this information.

REF 1 : Pg 7 line 16. You say that this station is ideally located, but don’t give any justification as to why it is ideal.

Authors : We will change the sentence as follows : “ This station allows monitoring the height of the urban atmospheric boundary layer (ABL) in the megacity.”

REF 1 : Pg 8 ln 6-7. “Only the last calibration: ” it is not clear what is meant by this sentence. Please clarify.

Authors : We will explain that “gas equilibrium issues implied retaining only the last calibration cycle for the calibration equation.”

REF 1 : Pg 8 ln 16. Please give a reference for the ICOS procedure.

Authors : The following reference will be added : Hazan et al, 2016 (Hazan, L.,

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Tarniewicz, J., Ramonet, M., Laurent, O., and Abbaris, A.: Automatic processing of atmospheric CO₂ and CH₄ mole fractions at the ICOS Atmosphere Thematic Centre, *Atmos. Meas. Tech.*, 9, 4719-4736, doi:10.5194/amt-9-4719-2016, 2016).

REF 1 : Pg 8 ln 20. How were the very local influences (that were removed) identified?

Authors : Very local influences were identified from the very short duration of the events (a few seconds to minutes) and from the large standard deviation of the CO₂ averages associated to these events.

REF 1 : Pg 8 ln 26. Please reference the WMO-X2007 scale.

Authors : The WMO-X2007 scale will be referenced to Zhao, C. L. and P. P. Tans (2006), estimating uncertainty of the WMO mole fraction scale for carbon dioxide in air, *Journal of Geophysical Research-Atmospheres*, 111(D8), 10.1029/2005JD006003. We will also provide the following link : https://www.esrl.noaa.gov/gmd/ccl/co2_scale.html/

REF 1 : Pg 10 ln 4. Please provide a link or reference for the Met Eireann met data.

Authors : The following link will be added : <http://www.met.ie/>.

REF 1 : Pg 10 ln 23. What met dataset was used in HySplit?

Authors : The Met dataset used in HySplit is the NOAA-NCEP/NCAR reanalysis at a 2.5° x 2.5° and 6 h resolution (<http://rda.ucar.edu/datasets/ds090.0>). This reference was already given in the Supplementary material but will be given in the main text.

REF 1 : Pg 11 ln 11. I don’t see the 1-sigma std devs on the plot. Did you mean to refer to figure 6 here?

Authors : Yes this is right, we will correct this.

REF 1 : Pg 11 ln 15. Please provide references to previous work that has discussed the biosphere and vertical dilution impacts on CO₂.

Authors : The following reference (dedicated to the TRN site) will be added : Schmidt

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et al, 2014 (Schmidt, M., Lopez, M., Yver Kwok, C., Messenger, C., Ramonet, M., Wastine, B., Vuillemin, C., Truong, F., Gal, B., Parmentier, E., Cloué, O., and Ciais, P.: High-precision quasi-continuous atmospheric greenhouse gas measurements at Trainou tower (Orléans forest, France), *Atmos. Meas. Tech.*, 7, 2283-2296, <https://doi.org/10.5194/amt-7-2283-2014>, 2014).

REF 1 : Pg 12 ln 2. "During daytime: " do you mean mid-afternoon?

Authors : Yes this is right, this will be corrected.

REF 1 : Pg 12 ln 3. "significant positive gradient". Perhaps "enhancement" would be a better word. (Also used elsewhere in the paper).

Authors : The correction will be made according to Ref.1's suggestion.

REF 1 : Pg 12 ln 12-14. Why does the lack of diurnal cycle at MHD make it a poor choice for background? If you are interested in examining the urban anthropogenic CO₂ source, then this is probably correct, but if you are interested in the diurnal variability of the continental biosphere signal, then it might be a good choice. Please explain/clarify.

Authors : This study is dedicated to the Paris megacity region (~150 km of diameter). The activity of the biosphere and other fluxes located between MHD and the Paris region impacts the amplitude of the regional " background " CO₂ diurnal cycle i.e. existing without the contribution of the Paris megacity fluxes. We do not want to take this remote contribution into account in our regional study. We propose to reformulate the text as follows: " 2/the MHD signal is several ppm below the continental signals, even at the rural site of TRN that was already shown not to be much influenced by the Paris megacity fluxes in Schmidt et al (2014). Thus, MHD does not reproduce the background diurnal variability of the regional stations and is clearly not a relevant background site for continental-Europe urban studies at the diurnal scale and at the regional scale (~150 km). "

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REF 1 : Pg 12 ln 22-23. Can you give an estimate of the magnitude of the biospheric flux through the seasons. It would be helpful to know how large it might be relative to the fossil fuel flux (even though the biosphere flux might be poorly constrained).

Authors : In this section, we referred to the Bréon et al (2015) paper as it gives the magnitude of the biospheric fluxes from the C-TESSSEL model and of the fossil fuel fluxes from AIRPARIF, through the seasons. From this reference and to answer to Ref.1's comment, we will add some quantitative information to our text, that will allow an easy assessment of the relative contribution of both types of fluxes at different periods of the year.

REF 1 : Pg 13 ln 14. I think you mean figure 5 and 6, not figure 7.

Authors : Yes this is right, the correction will be made.

REF 1 : Pg 15 ln 5-11. I don't see what this discussion of the vertical gradients adds to the paper. It could either be cut out, or a sentence added to explain why it is useful.

Authors : Vertical gradients are important to consider regarding mesoscale modeling studies. We propose to add the following sentence to this section: " Quantifying such vertical gradients is of interest since these gradients have to be correctly reproduced in urban mesoscale modeling frameworks for accurate CO₂ atmospheric inversion purposes. "

REF 1 : Pg 15 ln 13-26. The AIRPARIF inventory, I believe, is fossil fuel CO₂ flux only, whereas you measure total CO₂ (both fossil and bio). Could it be that the smaller weekday/weekend differences in your observation be due to the fact that biospheric fluxes are constant through weekdays and weekends? I.e. the difference between weekdays and weekends would be proportionally smaller in the total CO₂ observations than in the inventory, if there is a large (and constant) biosphere flux. Could this also explain why the GIF signal is more consistent between weekdays and weekends? I.e. perhaps the biosphere contribution is relatively more important at GIF than the urban sites?

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Authors : We agree with Ref.1 that this explanation is plausible. Furthermore, the influence of wind and of the CO₂ background signal likely contributes to the discrepancy observed from the emissions and the observations datasets. We will rewrite this section according to these considerations.

REF 1 : Pg 15 ln 28. Does this seasonal cycle include all or only some hours of the day?

Authors : This seasonal cycle includes all hours of the day.

REF 1 : Pg 16 ln 5-9. Please reference previous work that has discussed this phenomenon of seasonality in BL height, biosphere emissions and fossil fuel emissions. See for example: Denning, A. S., P. J. Rayner, R. M. Law and K. R. Gurney (1995). Atmospheric tracer transport model intercomparison project (TransCom). IGBP/GAIM report series report #4. D. Sahagian. Turnbull, J. C., P. J. Rayner, J. B. Miller, T. Naegler, P. Ciais and A. Cozic (2009). "On the use of ¹⁴CO₂ as a tracer for fossil fuel CO₂: quantifying uncertainties using an atmospheric transport model." Journal of Geophysical Research 114, D22302.

Authors : We will add both references to the text.

REF 1 : Pg 16 ln 17-21. Indeed, the CO₂ signals are higher in the winter, but the standard deviations do not seem to be higher in winter. Elsewhere in the paper, the higher standard deviations are used to identify higher anthropogenic emissions. Please justify why this is not the case here.

Authors : What we meant is that a signal with a higher standard deviation can be associated to the influence of fresher anthropogenic emissions, i.e. that are not well mixed in the atmosphere. We will make sure that this is clear enough throughout the paper.

REF 1 : Pg 17 ln 5-10. I don't think you can conclude that fossil fuel emissions are lower in summer from this dataset, since photosynthetic drawdown confounds the signal so

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strongly.

Authors : We agree that the first sentence of this section was confusing regarding the influence of the biospheric activity. We will reformulate as follows: "For all stations except GON, the annual minimum of concentration occurs in August and follows: 1/ the minimum of anthropogenic emissions as given by the Airparif inventory; and 2/ the maximum of the photosynthetic activity."

REF 1 : Pg 17 ln 21-24. Please explain and/or reference how the seasonal adjustment was performed. Reference previous work that discusses relationship between concentration and wind speed/ventilation.

Authors : The seasonal adjustment was done on the CO₂ hourly mean dataset of each station by : 1/ computing the annual mean of the dataset ; 2/ computing the monthly seasonal index for each month by dividing the monthly mean by the annual mean of the dataset ; 3/ interpolating the monthly seasonal index dataset to an hourly scale dataset ; and 4/ dividing the hourly dataset by the hourly seasonal index. We agree that several previous studies discussed the relationship between concentration and wind speed / ventilation and we will add their references in this section.

REF 1 : Pg 18 ln 20-22. Please clarify what the relationship is that justifies using the different wind speed regimes to identify local and remote emissions. Another sentence or two would help to follow the logic of doing this.

Authors : To make it simple, this depends on the strength of atmospheric mixing of local emissions against their ventilation and the advection of remote signals. For example, at windspeed less than 3 m.s⁻¹ (11 km.h⁻¹), it takes one hour or more for the air mass to pass over the center of Paris (~10 km of diameter) while at 8 m.s⁻¹ (~29 km.h⁻¹) it takes only about 20 minutes or less: the influence of local emissions vs. remotes ones on the passing air mass thus gets higher with decreasing windspeed. We will add a few sentences in this section to make it clearer.

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REF 1 : Pg 18 ln 25-29. Please expand this explanation a little more and/or reference the method, particularly for the square root transformation that has been applied.

Authors : We used the function polarFreq of the Openair software for R (http://www.openair-project.org/PDF/OpenAir_Manual.pdf) with the option “weighted mean”. We will rewrite these sentences to make it clearer.

REF 1 : Pg 20 ln 1-23. Exactly how close are MON and GON to CDG airport? Are there any other industrial or commercial facilities that could be causing this signal? In section 2.1.1. You stated that airport emissions are 4% of the total, whereas industrial emissions are 14%, so industrial emissions are potentially more important. Are CDG emissions large enough to plausibly explain the signal at both sites?

Authors : MON and GON are located about 13 km and 9.5 km away from the middle of the CDG airport. We agree with Ref.1 that we may have underestimated the influence of some industrial sites that are closer to the MON and GON sites than is the CDG airport. We will take this into account and will modify the text accordingly.

REF 1 : Pg 20 ln 22-23. How would carbon isotopes and specific emission tracers help to discriminate between airport and traffic emissions? Does jetfuel have a different isotopic signature than petrol/diesel?

Authors : This sentence is incorrect indeed and will be removed.

REF 1 : Pg 21 ln 3-11. See also previous comment – are the CDG emissions large enough at night and close enough to plausibly influence the GON site so strongly? It would be helpful to include Figure S2 in the main paper, since that shows the actual CO₂ data which is the main focus of the paper. If there is a limitation on the number of figures, Figures 3 and 4 could move to the supplementary material (since the wind directions are also shown in figure S2).

Authors : The CDG airport is operational day and night. But as mentioned earlier, we will better consider the influence of industrial emissions relatively to the one of the

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airplanes and CDG airport, and rewrite the text accordingly. We will include Figure S2 in the main paper. We think informative for the reading to keep Figure 3 in the main paper. We will move Figure 4 to the supplementary material.

REF 1 : Figure 5 is essentially repeated in figure 6. Could these two figures be combined?

Authors : The authors agree with Ref.1. To keep the information readable, we will combine both figures in one single figure with two panels a/ and b/.

REF 1 : Figure 9a and b could be combined by plotting 9a as an 8th panel in figure 9b.

Authors : The correction will be made according to Ref.1's suggestion.

REF 1 : Tables are mentioned in the text in a different order than the order of their numbering.

Authors : This will be corrected in the text.

Interactive comment on Atmos. Chem. Phys. Discuss., <https://doi.org/10.5194/acp-2016-218>, 2016.