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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Diurnal, synoptic and seasonal variability of atmospheric CO_2 in the Paris megacity area" *by* Irène Xueref-Remy et al.

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Answer to Referee 2 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."

General Comments

REF.2 : This paper analyzes nearly 1 year of CO2 data from the Paris megacity greenhouse gas measurement network. The analysis focuses on deciphering the CO2 observations on diurnal and seasonal time scales, and includes a careful examination of the influence of the atmospheric boundary layer height (ABLH), wind speed and direction, and local anthropogenic emissions on these signals. The measurement network contains six total sites across Ile de France spanning a range of conditions from rural to the Eiffel Tower in the heart of Paris. The report presents measurements that provide an important baseline for emissions from Paris and for comparison to other global megacities.

Authors : We thank Referee 2 very much for her/his careful reading of our paper and for her/his constructive comments. We answer to each point 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.

Specific Comments

REF.2 : The authors present a detailed analysis of the CO2 observations based on time, location, and wind speed/direction to infer the seasonal influence of local and background contributions at each site. This analysis is largely qualitative, but could be made far more quantitative and definitive if based around back trajectory analyses, such as those shown in Figure S1. We strongly suggest that the discussion of Section 3.1 be expanded and used to validate the conclusions of Section 3.5 which appear to be based on site wind measurements.

Authors : We will expand a bit more the discussion of Section 3.1 and will attempt to use this discussion to consolidate the conclusions of Section 3.5 as far as possible, but we think that the backtrajectories of Figure S1 deliver a qualitative information rather than a quantitative one. Indeed, we produced these backtrajectories using a public tool (HYSPLIT) with a 2.5° x 2.5° wind resolution, and this resolution is much too low to decipher differences between the Paris sites, that are distant by a few dozens of kilometers only. Furthermore, this low resolution can only give a gross estimate on the synoptic air mass fluxes between MHD or the Ruhr/Benelux area and the Paris megacity region. A quantitative analysis of the wind trajectories would require a dedicated model with a much finer resolution. This would require consequent work in terms of development, time calculation and analysis, and we therefore think that it would represent another study in itself, that is out of the scope of this paper.

REF.2 : The study concludes that the level of CO_2 enhancement varies with urbanization level local to the site; however, the paper does not directly discuss estimates of enhancement relative to background (or the concept of background) until much later in the paper. While diurnal and seasonal variability and the gradients between sites are the primary focus of this paper, background estimation is an important topic and which merits more introduction. Overall, there are two key points that should be incorporated: (1) the concept of background should be defined relative to the domain of interest and (2) a single site may not represent background CO_2 mole fractions under all meteorological conditions.

Authors : We define ''background" in the introduction as the CO_2 mole fraction without the contribution of the regional emissions (p. 3, l. 18). By regional, we mean the Paris megacity region i.e. a radius of about 100 km around the Paris center. We will make this spatial scale clearer to address point (1) mentioned above. Regarding point (2), we fully agree that a single site may not represent background CO_2 mole fractions under all meteorological conditions, as illustrated with our study of MHD in this paper, and in two previous papers of this team [Bréon, F. M., Broquet, G., Puygrenier, V., Chevallier, F., Xueref-Remy, I., Ramonet, M., Dieudonné, E., Lopez, M., Schmidt, M., Perrussel, O., and Ciais, P.: An attempt at estimating Paris area CO_2 emissions from atmospheric concentration measurements, Atmos. Chem. Phys., 15, 1707-1724, https://doi.org/10.5194/acp-15-1707-2015, 2015 ; Staufer, J., Broquet, G., Bréon, F.-M., Puygrenier, V., Chevallier, F., Xueref-Rémy, I., Dieudonné, E., Lopez, M., Schmidt, M., Ramonet, M., Perrussel, O., Lac, C., Wu, L., and Ciais, P.: The first 1-year-long estimate of the Paris region fossil fuel CO_2 emissions based on atmospheric inversion, Atmos. Chem. Phys., 16, 14703-14726, https://doi.org/10.5194/acp-16-14703-2016, 2016].

REF.2 : Additionally, the paper should use CO_2 enhancement values relative to some chosen background rather than absolute CO_2 values (eg 410 ppm) since the global background will surpass even these "elevated" values in the near future.

Authors : As a consequence of the previous point, the term ''background" remains more a concept than a quantity in our study and is not given as a numerical quantity value. We therefore do not report enhancements here (not even with a fixed value like 410 ppm). We reported dynamic enhancements in the above-mentioned studies of Bréon et al. (2015, Fig. 7) and Staufer et al. (2016, Fig. 4) but under specific meteorological conditions. We are trying to get a more general assessment in an on-going study, but this one is at early stage and clearly distinct from the research that we are reporting here.

REF.2 : The challenges of analyzing these measurements raises several priority questions regarding the Paris network. We note that the INFLUX network in Indianapolis, IN USA contains 13 towers for a smaller, less populated urban area and approximately 1/10th the emissions of Paris/IdF [Turnbull, Jocelyn C., et al. "Toward quantification and source sector identification of fossil fuel CO_2 emissions from an urban area: Results from the INFLUX experiment." Journal of Geophysical Research: Atmospheres 120.1 (2015): 292-312]. We would have expected some discussion of the density of the Paris network, the potential benefit of additional sites, and where they would ideally be located for maximum impact. This is particularly relevant for the "background" discussion since it is clear that Mace Head alone is insufficient for this analysis and that a full understanding of Paris CO_2 monitoring may well require observations from as far away as the Ruhr or the Benelux region.

Authors: Through the CO_2-Megaparis project, we were funded for 3 new sites on top of 2 existing national ICOS sites. We chose to deploy these new sites on the axis of the dominant winds (NE/SW) in order to optimize the amount of available data. The extension of the network for inverse modeling purposes is discussed by Staufer et al. (2016, Section 4.3) who conclude to the need of 8 more sites in the suburban/rural border of the city. Longer prospects are the topic of Wu et al. (2016) [Wu, L., Broquet, G., Ciais, P., Bellassen, V., Vogel, F., Chevallier, F., Xueref-Remy, I., and Wang, Y.: What would dense atmospheric observation networks bring to the quantification of city CO2 emissions?, Atmos. Chem. Phys., 16, 7743-7771, https://doi.org/10.5194/acp-16-7743-2016, 2016.]. Furthermore, in order to improve our understanding and modeling of the vertical transport of urban CO2 emissions, we mentioned in our conclusion the need to develop more measurements in the center of Paris, especially CO2 vertical profiles on the Eiffel tower (p.24 lines 13-15). We will extend the conclusion to synthesize all those elements.

REF.2 : Given the topographical similarities of Paris and Indianapolis, we were also surprised that more discussion was not presented comparing the CO2 concentration “plume” patterns from these urban areas.

Authors : If we compare Figure 2d of Turnbull et al. (2015) and Figure 7 of Bréon et al. (2015), we see enhancements of a few ppm in both cases. We can report this information, but the background is defined differently in each paper and the comparison remains rather qualitative and artificial. Also remember that we have much less sites in Paris than in Indianapolis.

REF.2 : Newman et al. [Newman, S., et al. "Diurnal tracking of anthropogenic CO 2 emissions in the Los Angeles basin megacity during spring 2010." Atmospheric Chemistry and Physics 13.8 (2013): 4359-4372] showed diurnal patterns for CO2 from the Los Angeles megacity, but there was no comparison made with these data. This is particularly relevant since Los Angeles CO2 emissions are well known to be dominated by vehicle/transportation and impart significant rush hour maxima (0700-1000 and 1500-1900) that are absent from all but the EIF signals in Paris. The arguments for winter vehicle emissions in Paris are not obvious from the figures as presented.

Authors : We agree and we will add some words in the paper dedicated to the comparison with the Newman et al (2013) study. In Paris, according to the AIRPARIF inventory for the year 2010, the CO_2 emissions are dominated by the heating sectors (43%, summing home and commercial emissions) followed by the traffic sector (29%). In winter, the heating sector is clearly dominant as the air temperatures are low (see Bréon et al, 2015, Figure 3). This may explain the differences observed between LA and Paris, although the vicinity of each station to traffic and heating sources must also be taken into account.

REF.2 : The Eiffel Tower (EIF) site offers unique observations that might be more fully exploited in future studies. Complete diurnal and day of week sampling at this site would enable greater understanding of variability across the network. Adding vertical profile measurements at eg 50, 100, and 200 m to complement the 300 m inlet height would add tremendously to understanding the ABLH/CO_2 linkages as well as providing different spatial sensitivity footprints within the Paris/IdF region. Increasing the sampling of meteorological fields at different heights would also prove valuable.

Authors : We thank REF.2 for this comment and we will mention more explicitely in our text that we plan to carry out such measurements within the Paris 2030 ''Le CO_2 parisien" project that was funded by Ville de Paris.

REF.2 : It would be useful to present the more details about the AIRPARIF inventory in the text, e.g., how it was constructed, its spatial resolution, etc.

Authors : The AIRPARIF inventory is well detailed in the Bréon et al (2015) paper. We will pay attention to better refer to this paper and will also add some key information about this inventory in our paper.

REF.2 : Comments on treatment of MHD and "background": P.7, line 6: MHD is described as a remote location. State here that this site was specifically evaluated as a potential background site.

Authors : We will do so.

REF.2 : See also comments below. P.16, line 3-4: The conclusion that MHD is not a relevant site for background on the seasonal scale does not seem to be fully supported by results. In some instances, a site that is classified as rural or peri-urban (or possibly urban) could represent background mole fractions under certain meteorological conditions. Selection of background can performed with using many methods, including meteorological filtering, analyzing tracer/tracer correlations, or evaluating the stability of observations. There is a significant body of literature detailing methods for selecting observations that represent background mole fractions (as an example, see Ruckstuhl et al., 2012, http://www.atmos-meas-tech.net/5/2613/2012/).

Authors : We defined our background as the CO2 mole fraction without the contribution of remote emissions. By remote, we mean out of the Paris megacity region (i.e. ~100 km around the center of Paris). Our observations show clear differences of several ppm between MHD and the rural site of TRN for example, which has been already demonstrated to be poorly influenced by the Paris megacity emissions. This shows that MHD is not a relevant background for the Paris megacity region. Regarding background calculation, we are aware of the complexity of the question and of the different methods available, but as we explained above this question is out of the scope of this paper. We will rewrite the text to make these points clearer.

REF.2 : P.18, lines 5-7: The conclusion here that MHD is not a relevant background site for Paris or other Western European cities also does not seem to be fully supported by the evidence. The definition of background depends on the domain of interest and also the timescale. For example, a single site may not be relevant for selecting background observations at all times and under all conditions. It is not clear whether there are ever any meteorological conditions that support MHD as a relevant local and/or regional background site. In general, the conclusions regarding MHD could be further supported by the evidence from the back trajectory and fine wind sector analysis (Sections 3.1 and 3.5.2) and/or the Supplemental materials (Figures S1 and S2).

Authors : We explained above why MHD is not a relevant background site for the Paris megacity region or other continental Western cities. We will make this clearer in the paper and make our best to rely also on the backtrajectories to consolidate our argumentation.

Technical Corrections

REF.2 : The manuscript could further benefit from more labeling figures to classify sites as “Urban” and “Periurban/Rural”.

Authors : We will do so.

REF.2 : Regarding analytical methods, the paper would also benefit from stating early on that all 7 sites (new and previously published) are on the same CO2 calibration scale (WMO X2007), use similar analytical procedures, and have relatively small uncertainties. This could be stated perhaps in the introduction or at the beginning of the methods section.

Authors : We will follow REF.2’s suggestion and will add a sentence about this earlier in the paper.

REF.2 : Introduction: Suggest presenting the site code QUA to associate this site with the ABLH measurements from the time they are first introduced.

Authors : We will do so.

REF.2 : Figure 6: May help to include inlet heights. Also, maybe label plots as Urban, peri-urban, rural/remote, etc.

Authors : We will do so.

REF.2 : P.4, line14: The reference Schmidt et al., (2014) first appears here, however it was not included in the list of references at the end of the paper.

Authors : This will be corrected.

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REF.2 : P.7, line 23: The authors mention the cell temperature of the analyzer at the EIF site was modified to undergo cell temperature set point at 60_C, however do not discuss what impact (if any) this may have on the results. Details of such analytical differences could be useful for others in the community conducting studies using similar analyzers.

Authors : No specific impact of the set point of 60°C was observed in the results.

REF.2 : Please be clear when meteorological data is measured vs. modeledâĖŸA ĖĞTe.g. add the word modeled to Figure 3 caption.

Authors : We will make this clearer.

REF.2 : Figure 5: might be useful to add inlet heights to the site key

Authors : We will do so.

REF.2 : Figure 7: What is the difference between the violet and red traces? Please describe in the text.

Authors : The violet trace uses only CO2 hourly data that are concomitant to ABLh hourly data. The red trace uses all CO2 hourly data points available for the relevant season. We will explain this in the text.

REF.2 : Figure 12, the wind roses highlighting CO2 concentrations and indicating the origin of the air masses being measured, was particularly interesting. Unfortunately, the discussion of this figure includes a lot of discussion of background, but it isn't clear exactly how the authors determined the background. I would also like to see explicit explanation of how the seasonal adjustments to the CO2 concentrations were made.

Authors : As we explained here before, the term ''background" is not quantitative in this paper, but is a concept and represents the contribution of remote fluxes (i.e. not from the Paris megacity area). We will make this clearer in our paper. 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. REF.2 : Table 4: The use of “N” is confusing since this is a percentage, not an integer. Consider renaming “coverage”?

Authors : We will modify according to this suggestion.

REF.2 : Page 10 Line 20: shouldn’t this section be titled, “Results and Discussion?”

Authors : Yes, this is right, we will modify according to this suggestion.

REF.2 : Page 12 Lines 28-32: What about the effect of inlet height? MON is much lower than TRN50.

Authors : We recognize that this point merits more consideration and will discuss it in the text.

REF.2 : Page 13 Line 6: Max interseasonal difference is higher than the mean annual afternoon dispersion: what does this imply?

Authors : This implies that the seasonal variability is higher than the mean dispersion of the fluxes.

REF.2 : Page 13 Line 10: “strong impact of regional CO_2 emissions variability:” why? Please elaborate a bit more.

Authors : We will elaborate this a bit more.

REF.2 : Page 14 Lines 5-34: Please put the seasons in the same order in the text and in the plot.

Authors : We will do so.

REF.2 : Page 18 Lines 21-22: Define local in terms of spatial scale.

Authors : Local is here define as “less than 10 km”. We will make this clear in the paper.

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