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Atmospheric Measurement Techniques Discussions

Interactive comment on "Munich permanent urban greenhouse gas column observing network" *by* Florian Dietrich et al.

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1 Responses to the comments of reviewer 2

We would like to thank reviewer 2 for reading our paper in detail and giving helpful comments. Below please find our answers:

2 General comments

Reviewer: In this study, Dietrich et al. report on a novel permanent urban greenhouse gas monitoring network using EM27/SUN spectrometers inside an automated enclosure system in Munich. They carefully describe the technical innovations from a previous design as well as results from a successful testing campaign and long-term operations. It is clear that the presented systems are a significant improvement and hold the potential to facilitate such measurements in many cities and regions in the future. The paper is clearly structured and very well written and it fits perfectly into the scope of AMT. Although the technical aspects are overall excellent, there is unfortunately a major point of concern that should be addressed before publication. The authors have made very strong statements that the manuscript itself does not address. For example, the claim that the presented systems and approach allows to determine urban greenhouse gas emissions "in any city worldwide". More instances of such sweeping statements are given in the specific comments section. I recommend that the authors revisit these statement and provide additional data and explanations to support them. On the other hand the author could also choose to let the fully supported and very impressive results, e.g. increased data availability, continuous operations during COVID-lockdown, tracking of XCO_2 enhancement changes speak for themselves.

Response: Thank you very much for your helpful and constructive feedback and your appreciation of our technical achievements. Regarding your critics, we agree with you that some of our statements regarding the emission assessment are too strong and not always supported by data or references. Therefore, we modified these statements throughout the text. Please see our comments in the specific comments section.

3 Specific comments

1. L1 – Consider removing "the"

   Response: We deleted "the"

2. L8 – This study does not establish that this technique by itself allows to quantify emissions. For example, how well can annual emissions be estimated when observations have a clear-sky (and maybe seasonal) bias.

   Response: Thank you for pointing this out. In our opinion, the properties of column measurements such as insensitivity to vertical redistribution of tracer masses and surface fluxes upwind the city, are a very important prerequisite to quantify emissions. In addition, we have the column measurements conducted upwind and downwind of the city, and the possible biases are canceled out by looking at the gradients. We slightly modified the formulation to "These column measurements and column concentration differences are relatively insensitive to vertical redistribution of tracer masses and surface fluxes upwind of the city, making them a suitable input for an inversion framework and, therefore, a well-suited candidate for the quantification of GHG emissions."

3. L21 – Although it is an impressive measurement system for total column CO_2 and CH_4, it seems far from proven that this technique and system as a "new standard for determining GHG emissions", given the complexity and challenges in urban environments.

   Response: You are right, this statement is probably a bit excessive. Therefore, we changed the sentence to: "In summary, our achievements in automating column measurements of GHGs will allow researchers all over the world to establish this approach for long-term greenhouse gas monitoring in urban areas."

4. L27 – Gurney et al. did not claim that urban areas contribute more than 70% of GHG emissions, but rather that "Cities account for more than 70% of global fossil

   fuel emissions". There are other non-urban and non-fossil fuel sources that contribute significantly to global GHG emissions, like land-use and land-use change (CO_2), agriculture (CH_4, N_2O), etc. Please correct this statement or provide a reference for your claim.

   Response: Thank you for pointing out this mistake. We changed it to "70% of global fossil fuel CO_2 emissions [...]"

5. L59 – Do all TCCON stations use this very high spectral resolution in their operations?

   Response: You are right, the resolution of TCCON measurements is lower (0.02 cm^{-1}). We changed it in the paper accordingly.

6. L64 – How can you be sure that you will be able to assess the effectiveness of mitigation strategies? Could the atmospheric modelling framework not be insufficient to achieve this, if for example urban heat island effects are not correctly modelled. Furthermore, are the planned emission reductions in Munich large enough to significantly alter XCO_2, XCH_4, XN_2O and other greenhouse gases.

   Response: Thank you for this note. We modified the language of this sentence a bit: "The combination of our sensor network with a suitable modeling framework will build the basis for monitoring urban GHG emissions over years, identifying unknown emission sources, validating satellite-based GHG measurements as well as assessing the effectiveness of the current mitigation strategies." The details of the modeling framework will be part of a follow up paper. Up to our knowledge so far, the challenges you mentioned can be solved.

   Furthermore, you are right: the absolute values of the column averaged GHG concentrations will not alter significantly based on the planned emission reductions. However, the emission information in our approach is included in the concentration gradients. To date, we can see a clear concentration gradient, with an estimated bottom-up CO_2 emissions of about 5.9 t per Munich citizen and year.

As the reduction goals aim to reduce these emissions by about 50% to 3 t per citizen and year until 2030, we are certain that our instruments will sense the changes in concentration gradients.

7. L147- Consider rephrasing for readability

   Response: We rephrased the sentence: "For controlling and automating the enclosure system, we developed two independent software: ECon and Pyra. The purpose of Econ is to control all safety and enclosure features that are monitored by the PLC, whereas Pyra is used to control the spectrometer and to automatically perform the measurements. Pyra also includes a user interface (UI) where the operator can set all parameters and observe the current state of the system."

8. L177 - See L147

   Response: Thank you. We reformulated the sentence: "Since the measurements are based on the spectral analysis of the sun, we have named the program Pyra, which is a combination of the programming language Python and the name of the Egyptian sun god Ra."

9. L219 - consider removing "respectively"

   Response: We deleted "recpectively".

10. L230 - What is meant by "pure emissions"? Does this refer to net emissions of the city of Munich?

    Response: We changed the sentence to "[...] this setup cannot be used to determine the emissions of the central city of Munich separately from its outer surroundings.".

11. L236 – "OCO-2" is repeated here

    Response: Thanks for pointing this out. We changed the second occurence of "OCO-2" to "OCO-3".

12. L252 (eq1) - Why was such a simplified fitting approach taken here, when more suitable and well-established methods are widely used to determine seasonal variations and trends in atmospheric CO_2 records? For example, as described in Nakazawa et al. 1997 and references therein (https://doi.org/10.1002/(SICI)1099-095X(199705)8:3<197::AID-ENV248>3.0.CO;2-C).

    Response: Thank you for suggesting us to use a more sophisticated fitting approach. We agree that our simple method cannot be used for a detailed and quantitative investigation of interannual variability in the CO_2 trend. For such purposes, a method as described in Nakazawa et al. (1997) would be necessary. However, we use the fitted curve just as a qualitative comparison and visualization in the plot. The obtained fitting parameters are not used in any further analysis. Therefore, we think that the simple fitting approach is sufficient for this case.

13. L257 - The word "hotspot" seems not to be optimal to describe data density

    Response: We changed it to "These high density data clusters represent our campaigns [...]"

14. L264 - It would be worthwhile to explain if this refers to 52% of all days since automation or all sunny/suitable days since automation, in any case a very impressive result.

    Response: Thank you for this comment. The two ratios refer to all days not only to suited days. As a result, we measured on average at least one hour every second day since the automation started. We tried to make our statement clearer by adding the following sentence: "In this calculation all days are taken into account, regardless of whether the measuring conditions were good or bad."

15. L281 - Adding the pollution rose plot for CO_2 enhancement of the station inside

the city could also be very interesting here to learn about the source distribution inside the city limits.

Response: Thank you for your suggestion. We added the concentration plot for the center station in the figure.

16. L293 – How much less data is available for southern station

    Response: We added a new table (Table 1) that includes the dates when the respective instruments started to measure in our network as well as the measured data points taken so far.

17. L296 - This study does NOT show the drastic impact on GHG emissions, but mere a decrease in local GHG enhancements. There are many other possible reasons for changes in GHG concentrations other then emission changes. It is reasonable to assume here that the concentration enhancement change is due to emission changes, but this should be stated carefully and other potential sources of uncertainty have to be included when referring to emissions.

    Response: Thanks for your suggestion. We attenuated our statements regarding our ability to determine emissions throughout the whole document. In this section, we changed the headline to "Influences of the COVID-19 lockdown *on urban concentration gradients*". Furthermore, we changed L296 to: "[...] showing the influence of such a drastic event on the *urban GHG gradients* of a city like Munich."

18. L302 - Please provide the R2 for this relationship. Also, looking at figure 14 it seems clear that CO_2 enhancements decreased strongly in week 6 and 8 already, well before the lockdown period, while congestion was above 25%, i.e. fairly normal. A scatter plot of the two quantities could be a useful addition in the supplemental information of this paper.

Response: Thanks for this valuable suggestion. We modified our statement regarding the correlation of our measurements to the traffic data and added the R2 value. The new formulation is: "The plot demonstrates that the lockdown had a significant impact on traffic flow. The CO_2 enhancements show a similar pattern throughout the first half of the year 2020. Based on the regression plot, there seems to be a correlation between the reduced traffic volume and the lower CO_2 enhancements (R^2=0.63). Both curves first decrease and then increase again after the strict restrictions were gradually loosened." As per your suggestion, a scatter plot was introduced to Figure 13.

19. L304 - See comment L296, L302, this study does not establish a decrease in emissions within Munich. Further modelling (including biospheric CO_2) and assessment of uncertainties seems necessary before the authors should claim that they have proven that their system is sufficient to track emission changes. The authors later refer these uncertainties, so they seem aware of this problem, so why make such a strong claim here? Being able to reliably track XCO_2 enhancement changes during COVID lockdown with an automated system is already an excellent achievement in itself.

    Response: Thank you. We have changed the statement (see response to comment of L302)

20. L327 - This statement completely ignores the potentially large impact on CO_2 concentrations by the urban biosphere, that has been found to be an important CO_2 sink (and sometimes source) in urban areas, for example, Miller et al. 2020 (PNAS, https://doi.org/10.1073/pnas.2005253117).

    Response: Yes, our statement is too simplistic here. We changed the sentence to "For that, the concentration gradients between the downwind and upwind stations are decisive, as they represent the anthropogenic emissions superimposed with biological processes."

21. L335: No data set of traffic emissions was presented in this paper. I agree that the seen decrease in congestion makes emission reductions extremely likely, but this should be stated carefully. Also the decrease does not seem to be concurrent.

    Response: We modified our sentence to: "The results show a *possible* correlation between the CO_2 column concentration gradients and the *traffic amount*, both of which appear to be drastically affected by the lockdown."

22. L342: It is unclear how this study has established that column measurements can be used in "any city worldwide". It seems apparent that the concentration gradients in the total column for smaller cities might be too small to detect reliably or the CO_2 emission signal might be masked due to biospheric uptake in cities in the tropics. What about cities with very strong aerosol loads, like Beijing, would the EM27SUN be able to penetrate dense smog?

    Response: Thank you for your comment. As mentioned before, we do not claim anymore that we can measure emissions but concentration gradients. We changed it in the paper accordingly. Based on that, we think that our approach can be used in many cities worldwide. We changed "any city" to "over a wide range of latitudes". The statement we want to make is that we developed the sensor system that is necessary to establish a permanent ground-based remote sensing network using EM27/SUN independent on the location.

    Furthermore, there exist FTS sites in large Chinese cities such as Beijing (Bi et al., 2018: https://doi.org/10.1007/s13351-018-7118-6) and Hefei (Wang et al., 2017: http://dx.doi.org/10.5194/amt-10-2627-2017).

With best regards,
Florian Dietrich on behalf of all co-authors

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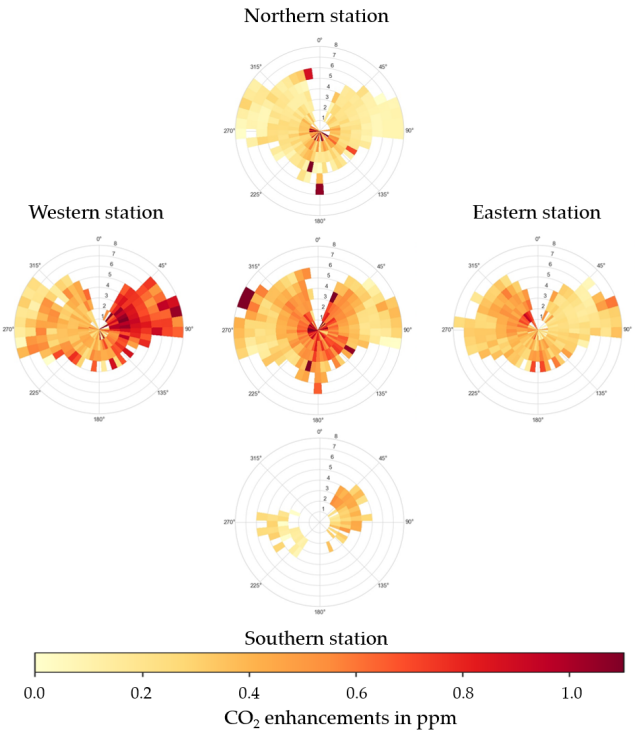

Fig. 1. Concentration enhancements over the background for each of the five stations displayed as a polar histogram.

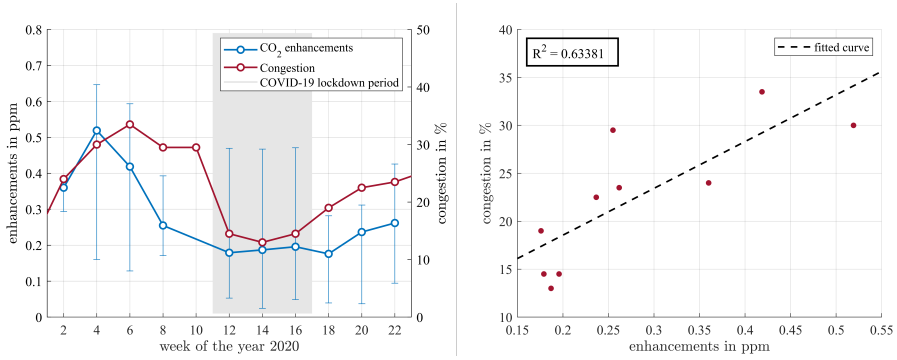

Fig. 2. Correlations between the CO$_2$ enhancements over the background measured at our inner city station in Munich, and the traffic amount represented by the congestion rate (time series + regression plot)