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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 1

We would like to thank David Griffith for thoroughly reading our paper and providing very helpful and insightful comments. Below, please find our responses to his comments.

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2 Summary

Reviewer: This paper describes a measurement system and early results from a set of portable, automated ground-based solar infrared spectrometers based on the commercially available Bruker EM27-Sun. Each spectrometer is housed in an autonomous housing allowing weather-proof operation and full automation. Five such spectrometers are deployed around Munich, Germany to deduce city-scale emissions of CO_2, CH_4 and CO from the upwind-downwind differences of total column amounts of these gases. The paper provides full technical details, building on an earlier 2016 publication. It represents a substantial instrumental development which would be of interest to anyone concerned with quantifying extended-source emissions such as cities or large point sources. It would require substantial effort and funding for others to duplicate the work, so I am pleased to see that the authors agree to make all technical plans, drawings and code available. It does leave me curious whether the authors have any plan to licence the system to a commercial provider – weather protection and automation for solar trackers and the EM27 used here and in TCCON and COCCON networks are not commercially available, but every installation needs one. The paper is clearly suitable for publication in AMT, after minor revisions and extensions and a few technical corrections.

Response: Thank you very much for appreciating our work and supporting its publication in AMT. Thank you also for suggesting the commercialization of our devices. We are currently looking into the possibilities to make our systems commercially available.

3 General comments

Reviewer: Section 5.2 describes essential side by side comparisons (they are not "calibrations" per se) amongst the 5 instruments and TCCON FTS at Karlsruhe. These

comparisons are of critical importance in evaluating small differences between upwind and downwind measurements, since any instrument bias would be interpreted as a gradient if not corrected. Yet no details of the comparisons are presented, and the reader has no idea of the uncertainty in the bias correction factors. It is essential to present the numerical details from all 6-monthly comparisons between instruments (and occasional TCCON comparisons). This could be done as a table of regression factors for each instrument pair and date. Only then can the reader assess the statistics of these comparisons – their magnitude, stability and reproducibility. The quantitative uncertainty will be essential for later modelling of the measured gradients in any Bayesian inversion scheme.

Response: Thank you for pointing out the missing quantitative comparison. We added two new tables (Table B1 and Table B2), which include the calibration factors for both the comparisons to the Karlsruhe instrument, which is calibrated to the TCCON standard, and the comparisons amongst our five instruments.

Reviewer: In section 5.3 and Figure 13 upwind-downwind data are compared, and at L302 the changes during Covid lockdown in 2020 are compared. However without the quantitative intercomparison data requested for section 5.2, it is impossible to assess the meaningfulness of these differences. How are the error bars on the CO_2 enhancements calculated (refer to 5.2 discussion)? I also do not agree that the data show a correlated drop in CO_2 enhancement with traffic congestion from weeks 4 to 12. CO_2 enhancement drop 4-5 weeks earlier, meanwhile the season is changing from winter to spring and presumably CO_2 sources other than traffic also change in this time, such as home, industrial and commercial heating. The interpretation is too simplistic. Thus I do not agree with the statement “These results prove that our network can detect changes in the urban emissions” – see also the conclusion around L 335. Based on the detail currently presented this conclusion is not valid. However this is not to say it is not possible. The data should be extremely valuable for such interpretations when

combined with a city-scale regional model such as described as being under development. I agree that this level of modelling and interpretation is outside the scope of this paper.

Response: Thank you very much for the valuable insights. After adding the requested information in section 5.2 regarding the accuracy of our measurements, it becomes clearer that the enhancements in Figure 13 represent a real signal. Furthermore, we clarified how the error bars in Figure 13 are generated: "The error bars show the 1σ standard deviation of all enhancements within the respective two-week period."

In addition, we refined our statement regarding the correlation of our measurements to the traffic data. 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." We also added a regression plot (Figure 13, right) showing the correlation between the CO_2 enhancements and the traffic congestion data (R^2 = 0.63), to provide evidence for our statement.

In the conclusion, we changed the sentence to: "The results show a *possible* correlation between the CO_2 column concentration gradients and the traffic emissions, both of which *appear to be drastically affected* by the lockdown."

Reviewer: Finally, I count the term "world's first" 5 times in the manuscript – this is excessive. I suggest it is OK and sufficient to point this out once-only in the abstract, conclusion, and introduction.

Response: Thanks for pointing this out. We deleted three of the five occurrences of "world's first".

4 Technical corrections

1. L15: Suggest rewording “as well as concentration gradients between sites upwind and downwind of the city.”

   Response: Thanks, we changed it according to your suggestion.

2. L59: TCCON measurements are made at a resolution of 0.02 cm^{-1}

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

3. L92: “Reed sensors in the inner cover COUNT these signals...”

   Response: We changed “are counting” to “count”.

4. L93: “Reed sensors INDICATE the absolute position.” There are several more cases of present perfect tense where simple present is normal English usage – a copy editor should pick these up.

   Response: Thanks for the hint. We changed “are indicating” to “indicate”. Furthermore, we tried to change all occurrences of present progressive to simple present.

5. L119: As described in the current text, the system could not operate for several hours around noon in the southern hemisphere unless the whole instrument is rotated 180° to point north, with software able to handle this switch. Presumably this is the case - I suggest the text be clarified to make this clear. Further, why is the range (30-300°) not symmetric around North?

   Response: Thanks for pointing this out. The range is not symmetric around North as the first mirror of the solar tracker is not centered at the rotation axis. Therefore, there is a slightly asymmetric behaviour of the morning and evening azimuth. We changed the text to: “That is why we designed our new cover so

that it can measure solar elevation angles up to about 80° and azimuth angles between 30° and 300° for setups at the northern hemisphere. The asymmetric azimuth angle range is due to the non-centered first mirror of the solar tracker. If the system is used in the southern hemisphere, it must be rotated by 180° and a setting must be changed in the software. These solar angles cover most places in the world."

6. L138: Unclear wording ("cannot" should be "can not"), I suggest either that small change or "They can control temperature to a constant level... as well as condense (not condensate) water vapour..."

   Response: We changed to sentence according to your suggestions to: "They can control temperature to a constant level of 25 °C under normal weather conditions in Uganda as well as condense water vapour to reduce the relative humidity inside the system."

7. L178: ...with two INDEPENDENT software COMPONENTS, OPUS and Camtracker, to control....

   Response: We changed the formulation according to your suggestion.

8. L207: Very little detail of the spectrum retrieval with GFIT is given. This is OK if it follows the Wunch and Hedelius references exactly, but any variations from those procedures should be described because they will impact on accuracy and precision. In particular, when is the analysis done? – vertical pressure-temperature-humidity profiles only become available after a few days, but the text sort-of implies the fitting is done the same day in a pipeline process.

   Response: Yes, we follow the GFIT retrieval as described in the references. We added a few additional information and modified the sentence about when we start the retrieval algorithm emphasizing that we have to wait for the vertical pressure profiles as you pointed out: "After about five days, when the a priori vertical pressure profiles from NCEP (National Centers for Environmental Prediction)

are available, the retrieval algorithm converts the information from the interferograms into concentrations. The retrieval algorithm used is GGG2014 (Wunch et al., 2015), which is also used to retrieve all the TCCON data. We applied the standard TCCON parameters, including the air mass independent correction factors (AICFs). The spectral windows for retrieving diverse gas species are slightly modified according to the EGI setup (Hedelius et al., 2015)."

9. L219: "respectively" is not needed here, remove.

   Response: We deleted "respectively".

10. L230: "pure emissions" is not quite the right wording, I suggest ".. this setup cannot be used to determine the emissions of the central city of Munich separate from its outer surrounds".

    Response: Thanks, we changed the sentence according to your suggestion.

11. Fig 8 L2: The urban area itself is largely contained (provide a %?) within the green inner dotted circle in the centre.

    Response: In Figure 8, we introduced the boundary of the urban area (black line). Furthermore, we changed the sentence to: "The urban area itself (indicated by the black border) is largely contained within the inner green dashed circle in the center, [...]"

12. L236: OCO-2 and OCO-3

    Response: Thanks for pointing this out. We changed it to "OCO-2 and OCO-3"

13. L254: with the parameters a to d to be fitted.

    Response: We changed the sentence to: "with the parameters a to d to be fitted".

14. L270: See general comments, this section should be expanded to include actual regression coefficient and statistics.

Response: Thank you. See response to general comments. We added two new tables (Table B1 and B2) that includes scaling factors and regression coefficients.

15. L292: Can you provide the actual starting dates and numbers of measurements, rather than “a little bit later” and “a little bit less”.

    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.

16. L302: See general comments.

    Response: See response to general comments. We changed our interpretation according to your advice.

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

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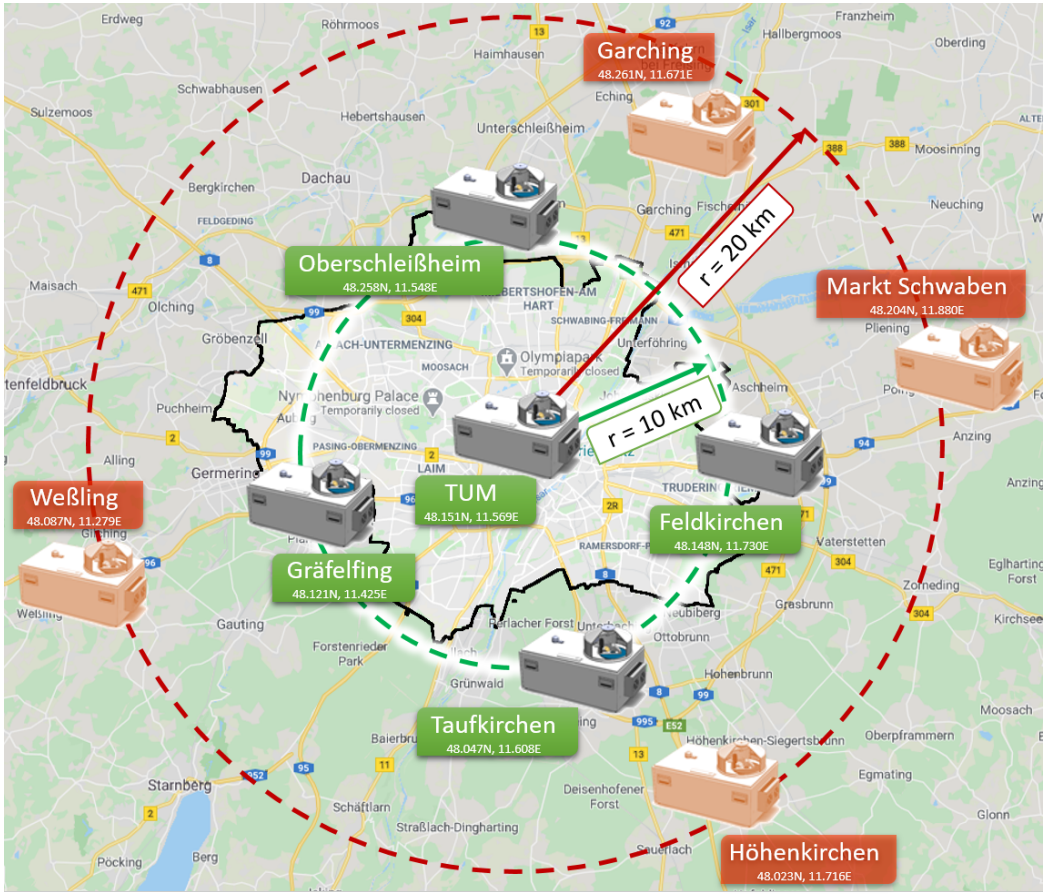

Fig. 1. Map of the greater Munich area together with the two different sensor network setups that have been implemented.

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