Atmos. Meas. Tech. Discuss.,
doi:10.5194/amt-2018-224-RC2, 2018

Atmospheric Measurement Techniques Discussions

Interactive comment on "The Fossil Fuel Emissions of Tokyo estimated directly from measurements of the Tsukuba TCCON site" *by* Arne Babenhauserheide et al.

Anonymous Referee #2

Received and published: 4 November 2018

The study uses four and a half years of ground-based column carbon dioxide measurements in Japan to estimate CO_2 emissions. Enhancement associated with selected wind directions are used to calculate the annual and month emissions of CO_2 from the nearby megacity, Tokyo, which are compared with a bottom-up emission inventory. Emission estimates are reasonable to first approximation, considering the many assumptions and uncertainties. The authors present a simple calculation that is applicable to other TCCON sites, and potentially to other species and measurement platforms. Overall, the study presents a simple method for determining emissions that could be used to calculate changes in emissions over time. Further analysis would be needed to determine when such a trend would be detectable given the large uncertain-

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ties. The manuscript focus of developing data processing methodology for atmospheric trace gas measurements fits well within the scope of AMT.

The manuscript is well written and easy to follow. However, prior to publication, the methodology would benefit from some expanded explanation and in-depth justification. Below are some specific major comments related to the methodology. In particular, the data preparation requires more justification, and clarification is needed about defining the perpendicular spread. Other comments are minor or technical in nature.

Major Comments:

1. Daily variability - I am not convinced that there is structure in the spray of data for Figure 2, particularly as the R^2 is very low for the curve fit. Could a box and whisker plot be overlaid on the inset to convince the reader there is structure? Care needs to be taken to avoid adding uncertainty or structure where there is none. Do the emission values change if a daily cycle is not included? The daily variability shown is not consistent with the daily variability described in Nassar et al. (2013).

2. Please expand on the one sentence at the end of Section 3 (pg 4, lines 13-14) that suggests why the seasonal and daily cycles were empirically chosen. If I interpret correctly, all the TCCON stations were used to determine the best "global fitting procedure". However, I disagree that all the TCCON stations will exhibit the same seasonal and daily variability, as it depends on their latitude, proximity to sources and type of sources impacting the sites. Consequently the curves to describe this variability might be different between stations. Therefore, I think it would be more valuable to describe the procedure to choose the optimal seasonal and daily curves for each site separately.

3. Is it reasonable to assume divergence perpendicular to wind direction does not occur (pg 8, line 10), but vertical diffusion occurs to complete mixing (pg 6, line 21)? It would also be instructive to provide an example of A_{aff} along one wind trajectory. Also, a diagram to help describe the "spread" would be valuable for visualization (e.g. Figure 1, below). The arc length (A to B, green dashed curve in Figure 1) may overestimate

the spread of Tokyo impacting Tsukuba. I suggest that using the cosine rule could be appropriate to estimate the Tokyo cross section measured by Tsukuba, which would in this case give 74.56 km (A to B, red line in Figure 1). Otherwise, please explain why the arc length is a better approximation of the spread.

4. Instead of average column wind speed (pg 8, line 6), partial columns could be used, seeing as the scaling factors have been determined (Figure 4). Partial columns could also account for the rotation of the wind direction at higher altitudes (suggested on pg 13, line 9).

Minor Comments:
(I) Abstract mentions "greenhouse gas emissions", but here only CO_2 is the focus. In general, be consistent with using CO_2 emissions, because "carbon emissions" could mean total carbon emissions from CO_2, methane, CO, VOCs, etc. unless otherwise defined. Also, I suggest you identify a "statistical-based approach" in the abstract.

(II) Introduction
- Pg 1, line 13: Clarify "fossil fuel burning emitters" to link this to Megacities like Tokyo. Also, what is the main contributor for Tokyo, vehicles, energy generation, or something else? Are these energy generation centers (e.g. coal-fired power plants) located within or outside the city? These explanations will prime the reader for why your method will work for a city like Tokyo.
- Pg 1, line 20: The "long term changes" are not addressed in this paper, although I was expecting it from this introduction. Perhaps bring in a comment to imply that with longer measurements than at Tsukuba currently, long-term changes in emissions can be investigated.
- Pg 2, line 1: Link the benefits of TCCON to the problems you have described previously. That is, what does the "highly accurate, precise, multi-year total column" allow you to do?

(III) Observations

- Pg 2, line 9: What is mean by "best" - best precision? highest time resolution?
- Pg 2, line 14: More information about the constant scaling factors (for what? why are they sometimes necessary?) and why you can ignore them.

(IV) Removing trend and annual cycles
- Figure 1: The yellow and magenta vertical lines are not necessary now the boundaries are explained in the text. Also, are the data displayed day averages, individual measurements, etc.?
- Pg 4, line 8: Add in how and why the degree 3 and degree 6 were chosen here, and why they are more appropriate than harmonics (which reflect orbital characteristics of seasons and days). Perhaps move lines 13-14 to here.
- Pg 4, lines 9-12: Clarify the postulation about wind direction and daily cycle and the impact on the analysis.

(V) Directional Dependence
- Figure 3: Some of the caption information could be moved to the main text.
- From pg 5, line 3 onwards I was unsure whether only the enhanced CO_2 concentrations were investigated further. If not, please clarify why the data is separated and then recombined.
- Pg 6, line 11: What does "most parcels in the lowest 2 km" mean for your analysis, e.g. does it support that any enhancements from those wind directions are likely due to Tokyo?
- Pg 6, lines 11-15: The radiosonde data information would be better in the observations section. Also, the relevance of the radiosonde data is unclear, e.g. was it used to produce Figure 4?
- Pg 6, line 19: What exactly is the volume of air assumed to contain enhanced CO_2? Is it the 0-1000 m described by Figure 4, or is it up to 2 km as described by the trajectories (line 11)?
- Pg 6, line 25: Is it possible to quantify the uncertainty due to mixing by comparing your uniform CO_2 assumption with an assumed vertical gradient?

(VI) Estimated source
- Figure 5: The vertical lines are very hard to see. Also, should it be "outside the urban influence" instead of "outside the background limits"?
- The discussion on pg 9, lines 5-6 about vertical divergence is a little disjointed and requires clarification as well as including a relevance statement.
- Reorder pg 9, lines 12-16 to describe equations in the order they appear.
- Pg 9, line 10: State the mean enhancement (126.4) here so the reader doesn't have to search.
- Equation 9, What is t_{CO_2}? Elsewhere you have use "t" for time. Also, there is an extra dot at the front of the equation.
- Pg 10, line 9: How does calculating 1 degree steps in the wind angle at Tsukuba mean you can compare with a gridded inventory? More description on this comparison methodology is necessary

(VII) Estimating Uncertainties
- Pg 11, line 13: How are changing the "center of mass" calculations performed? Does the Tsukuba to Tokyo distance change?

(VIII) Comparisons
- Figure 6: Label the axes. Add boundaries showing summed regions for Tokyo and Background.
- Figure 7: Need to add a second y-axis for the residuals from Figure 5.
- Pg 13, line 12: Clarify what is meant by "every reproduction".

(IX) Conclusions
- I suggest to mention that TCCON simultaneously measures other gases, so this method has the potential to be applied to other species.
- Pg 14, lines 22-23: There is also potential drawdown from about 180 degrees at high wind speeds (> 40 m/s) from the forested peninsula.

Technical Corrections:

Pg 2, Line 7: Do you mean this statistical method is "suitable for applying to long-term monitoring observations"?
Pg 2, Line 9: TCCON currently provides the best
Pg 2, Line 14: this study $\longrightarrow$ our study
Figure 2: Legend and text in Section 3 says the daily cycle is degree 3, Figure caption says degree 4.
Pg 4, Line 8: The long-term trend is fitted
Pg 4, Line 12: supplement Fig. 1 of this paper
Pg 5, Line 3: actual extent of Tokyo impacted wind directions.
Pg 6, Line 2: source of Tokyo (described further in section 5).
Figure 4, caption: including Ijima (2016). $\longrightarrow$ from the Ijima (2016) dataset.
Pg 8, line 6: average column wind speed within the boundary layer (0-2000 m), v_{wind}.
Pg 9, line 8: t_{aff} $\longrightarrow$ A_{aff}
Pg 11, line 3: ofd istances $\longrightarrow$ of distances
Pg 11, line 23: should the uncertainty be 33 not 38?
Pg 13, line 9: from the ODIAC model to

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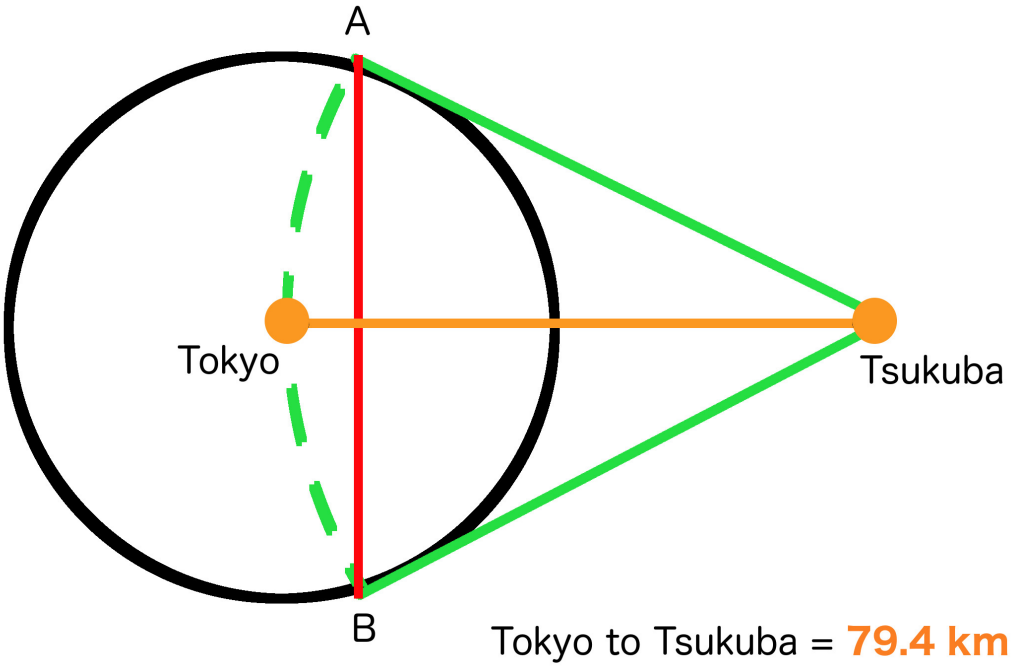

Fig. 1. Example diagram depicting idealized Tokyo city and calculation of city spread.

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