Quantifying CO_2 emissions of a city with the Copernicus Anthropogenic CO_2 Monitoring satellite mission

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Response to the Reviewer's Comments

We like to thank the reviewer again for their critical assessment and useful comments to improve the quality of the paper.

Reviewer 1

Reviewer Point P 1.1 — I appreciate the authors' efforts at clarification in the main text. The addition of the new Fig. 1 explaining the mass balance approach is very helpful in explaining the mass balance methodology to the reader.

As discussed in my previous review, the background/transport errors and diurnal sampling errors are significant sources of uncertainty in interpreting satellite data, and I see that the authors are in agreement as well. While I accept that the quantitative analyses can be incorporated in future analyses (albeit somewhat of a lost opportunity for this paper), I think the statements about the accuracy need to be qualified accordingly. Caveats need be added to the abstract, especially the part that starts with "The analytical inversion was able to estimate annual emissions with an accuracy of ..." Given the fact that key uncertainties were neglected, a clear qualifying statement needs to be incorporated that refers to the fact that background/transport errors and diurnal sampling bias would result in additional uncertainties. Note that the diurnal sampling bias applies to both the analytical inversion and mass balance methods.

Reply: We have revised the abstract and added the requested clarifications:

> Annual emissions were estimated by fitting a low-order periodic spline to the individual estimates to account for the *seasonal* variability of the emissions *but we did not account for the diurnal cycle of emissions, which is an additional source of uncertainty that is difficult to characterize*. The analytical inversion was able to estimate annual emissions with an accuracy of $<1.1\,\mathrm{Mt\,yr^{-1}}$ ($<6\%$) even with only one satellite*, but this assumes perfect knowledge of plume location and* CO_2 *background*. *The accuracy was much smaller when applying the mass balance approach, which determines plume location and background directly from the satellite observations.* At least two satellites were necessary for the mass-balance

approach to have a sufficiently large number of estimates distributed over the year to robustly fit a spline, but even then the accuracy was low (>8 Mt yr^{-1} (>40%)) when using the CO_2 observations alone. When using the NO_2 observations to detect the plume, the accuracy could be greatly improved to 22% and 13% with two and three satellites, respectively.

Reviewer Point P 1.2 — Secondly, Figure 1 needs to include the two-dimensional curve p(r). Otherwise it is not connected to equations 3 and 4.

Reply: We have updated Figure 1a accordingly:

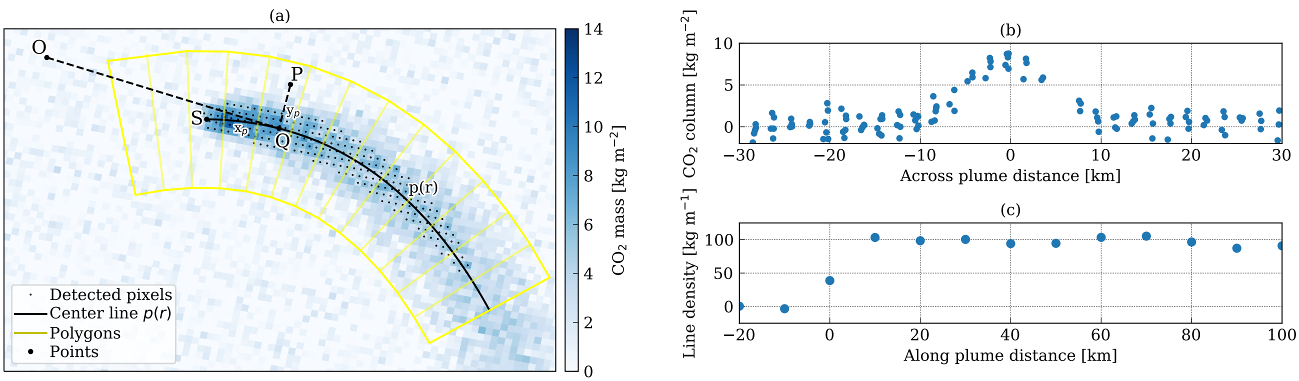

Figure 1. (a) Sketch of a CO_2 city plume with detected pixels and fitted center line. Random noise has been added to the CO_2 observations. The center of the city source is denoted by $\boldsymbol{S}$. The origin of the center curve is $\boldsymbol{O} = (x_o, y_o)$. For a satellite pixel $\boldsymbol{P}$, the across-plume coordinate y_p is the distance between $\boldsymbol{P}$ and $\boldsymbol{Q}$, and the along-plume coordinate x_p is the arc length from $\boldsymbol{S}$ to $\boldsymbol{Q}$. The yellow rectangles are the polygons used for computing the line densities. (b) Example of CO_2 mass columns in across plume distance for the polygon containing the pixel $\boldsymbol{P}$. (c) Line densities computed for each polygon in the sketch. The line densities are zero upstream of the source, build up over the city, and remain constant downstream of the city.