Referee #2:

The study by Zheng et al. uses the complete XCO_2 data record available from the OCO-2 satellite instrument to estimate the CO_2 emissions of 60 individual sources (cities, power plants, industrial areas) in China, accounting for almost one fifth of China's total CO_2 emissions. Several previous studies showed the potential of OCO-2 to detect and quantify strong point sources, but those studies were demonstrations rather than systematic analyses of OCO-2's ability to quantify regional emissions as presented here. The study by Zheng et al. is thus an important step forward. The applied methods are thorough and convincing. I particularly appreciated the conservative and careful selection of cases, for which emission quantification was safely possible. The results of the study nicely demonstrate the potential but also the great challenges offered by spaceborne CO_2 observations for emission quantification.

Emissions were estimated in the same way as in previous studies, i.e. by computing the integral amount of CO_2 in cross-sections through the plume multiplied by the wind component perpendicular to these cross-sections. However, there are novel elements that go beyond previous studies, notably the combination of a detailed emission inventory for China with a Gaussian plume approach where sources (e.g. cities) are not treated as individual plumes but as superpositions of multiple plumes emanating from individual area and point sources. Although the information from these super-positioned plumes was not used directly for plume quantification, it was used to attribute the plumes to specific emission sources, which was a critical step in the selection of suitable cases.

Overall, the paper is very well written and an important contribution to the growing literature on the quantitative interpretation of OCO-2 observations. I thus support publication after addressing the following points.

Response:

We thank the referee for the constructive and positive comments on our paper. We provide point-by-point responses as follows.

Main points:

- The title of the manuscript suggests that the study is about emissions of cities. However, the 60 plumes are not only from cities but also from "industrial regions". The authors should state explicitly how many of these plumes were representing emissions from cities, power plants and industrial complexes. This is important information for the planning of future satellite missions, since it is still not clear how well plumes from cities can be observed in comparison to those from power plants.

Response:

Among the 60 plumes that we analyzed, 33 plumes are from cities and the other 27 ones are from industrial regions. We now clarify this in the Sect. 3.1 as follow.

"The finally selected 60 cases include both densely populated urban areas (33 cases) and small industrial areas (27 cases) that gather many industrial plants."

We also revise the title of our paper to "Observing carbon dioxide emissions over China's cities and industrial areas with the Orbiting Carbon Observatory-2".

- The choice of a maximum distance of 50 km (page 4, line 100) between sources and OCO-2 track seems rather arbitrary. How does this choice affect the results? 50 km seems a rather short distance. More distant sources could contribute to the plumes and bias the corresponding estimates. The model-based study of Kuhlmann et al. (https://doi.org/10.5194/amt-12-6695-2019), for example, demonstrated that the plume of a power plant (Jänschwalde) 100 km away from a city (Berlin) could significantly overlap with the city plume in some cases.

Response:

Due to the steady-state assumption, the Gaussian plume model that was used to relate OCO-2 XCO_2 enhancements with emission sources is not reliable for long-range atmospheric transport (> 50 km, US EPA, 2015). We therefore prefer to restrict our analysis to the enhancements that can be related to sources within 50 km, thereby avoiding plumes originating from further away. For the cases that we selected, the agreement with the MEIC inventory (Fig. 3) suggests that we do not need to account for large emission sources outside the 50 km radius to interpret the enhancement.

- According to Bieser et al. (https://doi.org/10.1016/j.envpol.2011.04.030), roughly 90% of emissions from power plants occur between 200 m and 500 m above surface. How would emission estimates for power plants change using an average wind speed over this range rather than an average over 0–500 m (page 6, line 176)? Note that at the small distances between source and OCO-2 track considered in this study one cannot expect a homogeneous mixing of the plume over the depth of the PBL.

Response:

The 60 plumes that we analyzed are all from cities and industrial regions that have emission sources with various stack heights. The small industrial boilers and kilns, the major sources of CO_2 emissions in China, typically have smokestacks that are several tens of meters high. Therefore we used an average wind over 0–500 m to estimate the cross-sectional CO_2 fluxes from cities and industrial regions, which is the same configuration as Beirle et al. (2011) who also estimated city emissions (of nitrogen oxide) based on satellite observations.

Minor points and grammar:

- Page 1, line 18: Change "from the detailed China's emission inventory" to "from China's detailed emission inventory"

Response:

Corrected.

- P2, L34: "with the footprints" –> "with footprints"

Response:

Corrected.

- P2, L35: "natural CO_2 budget" -> "natural CO_2 budgets"

Response:

Corrected.

- P2, L36: "has allowed the initial insight" -> "has provided initial insight"

Response:

Corrected.

- P2, L46: "spaceborne CO_2 observation" -> "spaceborne CO_2 observations"

Response:

Corrected.

- P3, L64: "relies on the information about the wind" -> "relies on auxiliary information about winds"

Response:

Corrected.

- P3, L66: "provides the location" -> "provides the locations"

Response:

Corrected.

- P3, L75: "satellite sampling of OCO-2 capability" -> "sampling capability of OCO-2"

Response:

Corrected.

- P3, L77: "centered at the locations" -> "centered on the locations"

Response:

Corrected.

- P3, L86: Why should several XCO_2 anomalies belong to the same CO_2 plume? There is only a single transect per plume. Because of the moving windows?

Response:

The XCO_2 anomalies are those exceeding two sigmas of the spatial variability above the local average in each moving window. If a CO_2 plume crosses an OCO-2 track, the OCO-2 should observe a plume transect with XCO_2 enhancement, where there could be several XCO_2 anomalies larger than two sigmas above the local mean, although they correspond to the same CO_2 plume.

- P4, L91: "8 footprints if no is missing" -> "8 footprints if none is missing"

Response:

Corrected.

- P4, L93: "within CO_2 plume" -> "within the plume"

Response:

Corrected.

- P4, L104: Only a detail: Why is the along-wind distance measured in kilometres, but the across-wind distance in meters?

Response:

Here *z* (along-wind distance) has to be specified in kilometers to give $a \cdot z^{0.894}$ in meters (Bovensmann et al., 2010).

- P5, L136: I think it would be clearer to state "We find 49,322 cases with local XCO_2 enhancements". It wasn't clear to me initially whether these were individual pixels or plumes.

Response:

Corrected.

- P5, L144: 50 km is not an appropriate scale for synoptic transport. I suggest to simplify to ".. or transport of CO_2 over a longer distance"

Response:

Corrected.

- P5, L148: "in space to make it difficult" -> "in space making it difficult"

Response:

Corrected.

- P6, L153: It would be better to write "Although the total number of selected cases is small, it is several times larger .."

Response:

Corrected.

- P6, L163: "at about local 13:30" -> "at about 13:30 local time"

Response:

Corrected.

- P6, L164: "part of OCO-2 ground track" -> "part of the OCO-2 ground track"

Response:

Corrected.

- P6, L175: "CO_2 fluxes" -> "CO_2 flux"

Response:

Corrected.

- P6, L178: Why shifted by 1°? Maybe it would be clearer to state "shifted by 1° in this case".

Response:

Corrected.

- P7, L186: How was the uncertainty of the hourly emission rate of Qinhuangdao determined? Does the MEIC inventory include uncertainties?

Response:

Yes, the MEIC inventory includes uncertainties of city emission estimates (Zheng et al., 2018).

- P7, L194: There were 4 cases where the same source was quantified twice. It would be good to know how consistent those double quantifications are with the estimated uncertainty of <24%.

Response:

The emissions from 3 cities were quantified twice over the same season (i.e., cold or warm) at the same or different years. The consistency in these estimates for the same city, defined as the difference between one estimate and the two independent estimates mean, is 15–24%.

- P7, L203ff: The interpretation of the small differences of 5-6% between satellite based estimates and MEIC in different seasons is pushed too far in this section considering the uncertainties. At least the arguments should be presented as possible explanations rather than as facts (e.g. write "could be due to" rather than "are due to"). The over-interpretation of the results culminates in the statement that human respiration accounts for 38% of the (5.5%) difference and that the remaining difference could be due to a bias in MEIC. The numbers deduced from the satellite observations are not sufficiently robust to speculate about a bias in the inventory as small as 3 percent. Uncertainties in the method (notably the assumption that the 0-500 m average wind speed is representative) could easily explain such differences, probably also differences in the results between summer and winter since vertical mixing is different in these seasons.

Response:

We rewrote this paragraph as follows according to the reviewer's suggestion.

"The differences in the results between cold and warm seasons could be due to uncertainties in the emission estimate methods of both our OCO-2 based inversion and the MEIC inventory. The satellite-based larger estimates in the cold season could be partially due to the fact that human respiration contributes to urban CO_2 fluxes while not included in the MEIC inventory of fossil fuel and cement emissions. We make a rough estimate of the metabolic CO_2 release by multiplying an emission factor of 0.52 t-CO_2 yr^{-1} $person^{-1}$ (Prairie and Duarte, 2007) by the population living in each emitting area. The results suggest that human metabolic CO_2 emissions explain 8% of the larger satellite-based emission estimates on average in the cold season. The remaining difference could be due to the assumption that the 0-500 m average wind speed is representative of the transport wind in the plume diffusion, the natural processes like plant respiration, or the slight growth of fossil fuel emissions since 2013, but could also reflect some bias in the MEIC estimates. In the warm season, despite human respiration emissions, the satellite-based inversions give lower emission estimates possibly due to the carbon uptake by plants damping the XCO_2 enhancements (Mitchell et al., 2018), which makes anthropogenic emission signals not easily separated from the background in the satellite-based inversions."

- P8, L233: "principle, not all" -> "principle, but not all"

Response:

Corrected.

- P8, L235: "densely urban areas" -> "densely populated urban areas"

Response:

Corrected.

- P8, L44: The last section should be renamed to "Conclusions".

Response:

Corrected.

- P9, L271: "with less CO_2 inventory infrastructures" -> "with less advanced CO_2 inventory infrastructures"

Response:

Corrected.

- Figure 1: The blue bar should be called "XCO_2 anomalies" rather than "XCO_2 outliers"

Response:

Corrected.

References

Beirle, S., Boersma, K. F., Platt, U., Lawrence, M. G., and Wagner, T.: Megacity Emissions and Lifetimes of Nitrogen Oxides Probed from Space, Science, 333, 1737-1739, doi: 10.1126/science.1207824, 2011.

Bovensmann, H., Buchwitz, M., Burrows, J. P., Reuter, M., Krings, T., Gerilowski, K., Schneising, O., Heymann, J., Tretner, A., and Erzinger, J.: A remote sensing technique for global monitoring of power plant CO_2 emissions from space and related applications, Atmos. Meas. Tech., 3, 781-811, doi: 10.5194/amt-3-781-2010, 2010.

US EPA: Revision to the Guideline on Air Quality Models: Enhancements to the AERMOD Dispersion Modeling System and Incorporation of Approaches to Address Ozone and Fine Particulate Matter. Tech. rep. US Environmental Protection Agency #2060-AS54. https://www3.epa.gov/ttn/scram/11thmodconf/9930-11-OAR_AppendixW_Proposal.pdf, 2015.

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