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Interactive comment on "Constraining fossil fuel CO_2 emissions from urban area using OCO-2 observations of total column CO_2" *by* Xinxin Ye et al.

Anonymous Referee #3

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This study investigates the potential of observations of total column CO2 (XCO2) from a satellite of type OCO-2 to quantify CO2 emissions from individual cities. The study is based on high -resolution (kilometer scale) urban plume simulations with WRF-CHEM used to conduct observation system simulation experiments and for comparison with real OCO-2 observations.

The topic is highly relevant and timely as several new CO2 satellite missions are currently being planned and more and more applications of OCO-2 data are being publishes. The manuscript is thus a welcome contribution.

The manuscript is fairly well written and the methods, centered around comprehen-

sive model simulations, are generally sound. The study presents many interesting and innovative aspects that clearly deserve being published. In particular, the study investigates uncertainties in the emission estimates related to transport uncertainties by stretching/squeezing or rotating the simulated model fields, applies an ensemble approach for basin cities, and investigates the influence of biospheric fluxes using an ensemble of biosphere flux models downscaled to high resolution for the simulations. The simulation setup is impressive and the analyses presented are comprehensive.

Despite these positive aspects, I also have a few concerns primarily related to the way the study is presented and the conclusions that are drawn as detailed in the following.

Main points:

Based on the abstract, a reader may conclude that OCO-2 is a satellite highly suitable for quantifying CO2 emissions from cities , but OCO-2 has not been designed for this purpose and is clearly far from ideal. The main problem of the manuscript is that the severe limitations of OCO-2 in terms of temporal and spatial coverage are not clearly discussed and that, therefore, a much too optimistic picture is drawn of what can be achieved with such a satellite. The only sentence in the introduction addressing the issue of coverage is the following fairly neutral statement: "discernible CO2 emission imprints can be limited due to the contamination by clouds and aerosols and limitations of spatial-temporal sampling coverage for local sources related to the revisit cycle of sun-synchronous polar orbit and the narrow tracks". OCO-2 has about 15 orbits per day, each with a swath of approx. 10 km. In 1 day it thus covers a total east-west extent of 150 km. For comparison, the circumference of the Earth is about 40'000 km, i.e. OCO- 2 would take 266 days to sample each point on the globe (at the equator) at least once. But OCO-2 has a 16 days repeat cycle which means that many points on the globe will never be observed at all. To measure the plume of a city does not necessarily require flying directly over the city (except for basin cities), but the overpass should be close to have sufficient signal and to be able to unambiguously attribute the plume to its source. On page 2, L35, the authors state that "OCO-2 pioneered the

contiguous high-resolution mapping of global CO2 concentrations", which needs to be changed. A swath of 8 pixels across-track definitely does not qualify OCO-2 as a "mapping mission". OCO-2 takes high-resolution measurements along a narrow line. Its sampling strategy is much closer to a 1D than a 2D mission, which is also why this study analyzes CO2 along individual (1D) lines and not in (2D) images of entire plumes. It is important to make this distinction because several true imaging missions are currently being planned including geostationary and polar orbiting missions.

There are also other reasons why the overall tone of the manuscript is much too optimistic: On page 3 the manuscript states that "a handful of cities with different typical XCO2 features in XCO2ff enhancements" were selected, which gives the impression that the selection was more or less arbitrary and that any other combinations of cities might have worked equally well. However, the authors have picked highly ideal cities with a) very large emissions, b) little interference with biospheric fluxes (Riyadh and Cairo), c) very low average cloud cover, and d) nicely isolated from other cities avoiding overlapping plumes. For the study of interferences with the biosphere, the Pearl River Delta region has been selected, one of the most densely populated regions where, again, anthropogenic emissions are unusually large compared to biospheric influences. There are good reasons for selecting these cities because OCO-2 offers many opportunities to observe their plumes, but it has to be openly communicated why these were selected and that the challenges for most other cities (probably for 99% of all cities of the globe) will be much larger due to frequent cloud coverage, strong interferences with biospheric fluxes (especially during summer coinciding with periods of low cloud cover and hence good observation opportunities), poor coverage due to the OCO-2 orbit geometry and narrow swath, overlapping plumes, plumes below the detection limit etc. Based on the OSSEs it is concluded that emission uncertainties are constrained to less than 15% with at least 9-10 tracks for plume cities and even down to 5% for a basin city, and that it would only take about 2.1-2.4 years to collect a sufficient number of tracks with an OCO-2 type instrument. However, this conclusion is only valid for the unrealistic case of negligible observation uncertainties , perfectly

known background and emission distributions, and non-existence of clouds. In reality, the magnitude of the plumes will typically be in the low ppm to sub-ppm range and hence in a similar range as instrument noise, and clouds will frequently obscure the view. Fitting real observations to the simulations is thus much more difficult and many more overpasses will be needed to reach such a low uncertainty. This is also nicely demonstrated by the real cases presented in Section 3.4, where three overpasses over Riyadh provide median emission scaling factors differing by almost a factor of two (between 1.58 and 2.94), and the histograms even include negative emissions. These real OCO-2 observation cases would offer a nice opportunity to place the previous theoretical OSSE analyses in context and to explain the additional challenges, but there is no discussion of this at all.

Thus, my general recommendations are

a) better emphasize the challenges as well as the limitations of OCO-2

b) stress clearly in the abstract and conclusions that the OSSEs were conducted under idealized conditions neglecting instrument uncertainties and that the convergence to XX% with YY tracks only refers to the contribution of transport uncertainties under these conditions

c) explain that the cities selected in this study were chosen for their ideal properties to demonstrate the potential of OCO-2, but at the same time point out that for many other cities it will remain a challenge to quantify urban emissions with sufficient accuracy.

d) place the results obtained for the real cases in context with the OSSEs

Finally, I would like to point out that Figure 10 can not be published in its current form, since the lower part of the figure has been borrowed from another publication most likely violating copyrights.

Small issues:

Page 1, Line 21: Change "in urban and rural area of Pearl River Delta" -> "in the urban

and rural area of the Pearl River Delta"

P2, L2: Although 70% of global CO2 emissions may be due to energy consumption in cities, a considerable (yet probably unknown) fraction of these emissions do not occur inside the cities but outside in power plants delivering the energy for the cities. This is usually forgotten when just citing this number.

P2, L6: "few exception such as (Gurney et al, 2012)" -> " few exceptions such as Gurney et al. (2012)". There are actually many other locations where the reference is not properly formatted.

P2, L8: "spatial explicit" -> "spatially explicit"

P2, L15: "Inverse modelling, or top-down approach assimilate" -> "Inverse modelling, often referred to as top-down approach, assimilates"

P2, L19: "by inversion method" -> "by inversion methods"

P2, L26: "are detected" -> "have been detected"

P2, L31: "background area" -> "background areas"

P3, L10: Change to ".. have been identified as major sources of .."

P3, paragraph 2: One more important challenge needs to be added, namely the temporal variation of emissions at diurnal to seasonal time scales, which can not be fully captured by a satellite leading to potential biases in the emission estimates (both to diurnal and seasonal sampling biases).

P3, L33: "is referred to" -> "was referred to"

Section 2.2.2: It needs to be mentioned here that no temporal variability of emissions was considered. Furthermore, it should also be mentioned that all CO2 was released at the surface or, if not, how emissions were distributed vertically.

P6, L16: "using ensemble" -> "using an ensemble"

P6, line 29: "an d o" -> "and o"

P6, line 32: What do you mean by "artificially"? This doesn't seem to be the right word here.

P7, L19: "the diffusions of fossil-fuel CO2 are" ->" the diffusion of fossil fuel CO2 is"

P7, L26: "in urban canopy" -> "in the urban canopy"

P7, L33: "Los Angeles are used" -> "Los Angeles were used"

P7, L34: "observations are derived" -> "observations were derived"

P8, L22: "is the approximately overpassing time" -> "is the approximate overpassing time"

P9, L33: "with a stronger northern" -> "with a too strong northern" (sounds better to me)

P10, L3: references appear twice

P10, L12: "characterized with" -> "characterized by"

P11, L6: "and Cairo linear" -> "and Cairo a linear"

P12, L13: "this suggest" -> "this suggests"

P12, L19: Please add CarbonSat (Buchwitz, M., M. Reuter, H. Bovensmann, D. Pillai, J. Heymann, O. Schneising, V. Rozanov, T. Krings, J. P. Burrows, H. Boesch, C. Gerbig, Y. Meijer, and A. Loescher, Carbon Monitoring Satellite (CarbonSat): assessment of atmospheric CO2 and CH4 retrieval errors by error parameterization, Atmos. Meas. Tech., 6, 3477-3500, 2013).

P13, L18: "across in urban" -> "across the urban"

P14, L13: "using Monte Carlo" ->"using a Monte Carlo"

P14, L25: "Similar magnitude" -> "A similar magnitude"

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