We thank the referees for their comments. The main changes to paper are that we have 1) clarified the aim of the paper as requested by Anonymous Referee #1; and 2) added a discussion section as requested by Anonymous Referee #2.

Anonymous Referee #1

> The authors present global anomaly maps of the CO2 column in the atmosphere from measurements of the OCO-2 satellite. They show that the main characteristics of the maps (coherent signals from year to year, positive anomalies in the presence of surface emissions, negative anomalies in the presence of surface sinks) are consistent with current model simulations. They could also have noted that they are all consistent with the XCO2 literature (e.g., Olsen and Randerson, 2004, doi:10.1029/2003JD003968; Keppel-Aleks et al. 2011, doi:10.5194/acp-11-3581-2011, 2012, doi:10.5194/bg-9- 875-2012, etc.), and even with the OCO-2 literature (e.g., Eldering et al., 2017a,b, doi:10.5194/amt-10-549-2017, doi:10.1126/science.aam5745 and references therein). In this context, the aim of the authors is not clear: is their paper the presentation of a teaching material, a new evaluation of the OCO-2 XCO2 retrievals, a statement that no more discoveries are expected on XCO2 from OCO-2? The authors must clarify and justify their message.

We now clarify our aim and message in the end of the introduction section. We also cite the references indicated. Related also to this, we added a full discussion section as requested by Ref. #2 (see the answer to the first point of Ref. #2) including the interpretation of the results in a broader context. We hope that it is now clear this paper is not a presentation of 'teaching material,' and we certainly do not want to state that no more discoveries are expected. We added this text:

"Our previous study (Hakkarainen et al., 2016) introduced the concept of XCO2 anomaly and analyzed the first 18 months of OCO-2 measurements for three selected areas in the Northern Hemisphere, together with satellite-based NO2 observations and ODIAC (Open-source Data Inventory for Anthropogenic CO2) emission inventory. Previous studies also described the seasonal variability of CO2 spatial features based on monthly means from OCO-2 observations (Eldering et al., 2017a, b) and model results (Olsen and Randerson, 2004; Keppel-Aleks et al., 2011, 2012).
The aim of this paper is to provide an improved global (60◦ S–60◦ N) view on XCO2 anomalies as seen by OCO-2 for three full years 2015–2017. We now analyze the annual anomaly patterns and seasonal variations and compare the observed anomalies to modeled enhancements, estimated fluxes and SIF (indicating the occurrence of photosynthesis). We also investigate the effect of the different assumptions on the calculation of anomalies (e.g., latitudinal and sampling effects) and demonstrate the capability of the method to analyze small scale emission sources."

> p. 3, l. 10: repeated from p. 2, l. 30.

Removed.

> p. 3, l. 15: looking at Wunch et al. (2017, Table 3) the plural to "differences" is not justified and should be replaced by a singular (the median differences among the sites may be greater than 0.4 ppm and the RMS differences among the sites may be greater

than 1.5 ppm). In fact, site-level statistics would be more relevant here than global figures alone, because the authors examine spatial gradients rather than average levels.

We now use singular.

Figure 1: the area definition for the background estimation is missing.

We added this text in caption: "*We use the Northern and Southern hemisphere (60° S–0° S and 0° N–60° N) over land as background areas.*"

p. 4, l. 5: The authors explain that the independence of their estimate to a priori fields is a strength, but why does this independence matter in what is presented? Would this still be a strength if some a priori field was more accurate?

Independence of a priori field is essential if we want to understand the spatial patterns (and added value of the satellite observations, no matter how accurate the a priori fields might be). We now write: "*The independence of a priori fields is critical in order to resolve sub-regional patterns.*"

p. 9, l. 2-3: do all inverse modeling systems estimate scaling factors to fluxes? I would have thought they estimate simple flux increments.

We refer here to CarbonTracker as a concrete example and clarify the sentence: "*In addition, in systems like CarbonTracker, the scaling factors for a priori biospheric fluxes are estimated over "ecoregions," and the sub-regional patterns seen in the flux maps come from external modeling.*"

p. 9, l. 8: very attractive for what?

We rephrased as: "*The anomaly approach used here has several advantages*…"

p. 9, l. 11: need to quantify "very sensitive".

We removed this part.

Anonymous Referee #2

The authors present a novel technique to determine CO2 anomalies from the OCO-2 satellite instrument, which in principle is not designed to detect such variations. This work has been first published by them in GRL (2016). In their GRL paper, the authors indicated a number of potential improvements to their technique, which have been taken into account in the present paper. They have provided a sensitivity analysis of their method and further investigated the impact of various assumptions. Besides refining their technique, the results are now covering 3 instead of 1.5 years providing a picture into inter-annual variations. They now also present seasonal variations and a global picture as opposed to selected areas in their GRL paper. They made a first attempt to interpret their results by comparing them with vegetation fluorescence (SIF) and looking at model results from biogenic and fossil fuel CO2 signals.

In general the paper in its current form misses an essential element. It stays too much at the level of GRL, which is generally more like a news item and possibly requires less attention to the scientific value of the results. On the other hand, the paper is now also too much focusing on the actual method, which makes it lean toward an AMT paper. The paper requires the inclusion of a discussion section for the scientific community. The introduction clearly highlights the importance of CO2 and measures required to reduce greenhouse gas emissions (COP21). Presumably, this is also one of the reasons the authors compare model results of separated biogenic and fossil fuel signals with their observed anomalies. The authors should include in the discussion section an interpretation of the results and reach out to the modelling community highlighting how these results can be used in their models (for reference see Bergamaschi et al, 2018). This would enhance the relevance and context of the paper making it suitable to ACP were it is in its right place. They shall also provide a vision for future use of this technique combining several satellite missions and what this means for future planned missions, e.g. OCO-3, GOSAT-2, MicroCarb, GeoCARB, Chinese and European wide- swath constellation plans. Can it be applied to one or a combination of these missions? Based on the new/elaborated discussion section, the authors need to update the abstract, which now only hints in its last sentence to 'a potential'.

We agree. We have added a new discussion section for the scientific community where we discuss the issues indicated. We updated also the abstract. Discussion:

"Current CO2 missions have been primarily designed to extend the spatial coverage of the ground-based atmospheric observation networks and to improve the model estimations of biospheric fluxes on regional scale. The COP 21 Paris agreement emphasizes the need to monitor anthropogenic CO2 emissions over a range of scales (Bergamaschi et al., 2018).
The anomaly approach presented here exploits the intrinsic value and capabilities of satellite-based CO2 observations for mapping anthropogenic and natural emission patterns, beyond their application as model input information. The observed consistency between satellite-based XCO2 anomalies and model outputs (distinguishing fossil fuel and biospheric contributions) demonstrates the capability of satellite observations for describing the CO2 spatio-temporal variability and, in particular, for detecting anthropogenic CO2 emission patterns. The results presented here also provide a proof of concept for future planned XCO2 missions, such as OCO-3, GOSAT-2, MicroCarb, GeoCARB, and the Chinese and European wide-swath constellations. The same anomaly approach can be easily applied to instruments that fly in near-polar, sun-synchronous orbits, however, adjustments to background definition are needed for instruments operating on the International Space Station (e.g., OCO-3) or on geostationary orbit (e.g., GeoCARB) due to the possible influence of diurnal variations and spatial coverage. Further applications of this method could combine anomalies from similar platforms, e.g. belonging to the same constellation.
Future plans include the application of the anomaly approach to local scale analysis, as demonstrated here and tested e.g. by Wang et al. (2018) for several emission sources over northern China. Combining XCO2 anomalies with high-resolution space-based observations of short-lived gases (such as NO2) like those from TROPOMI/S5P, will provide further insights about anthropogenic CO2 spatial patterns. Related to such applications, the results presented here highlight the need for satellite observations with good accuracy and dense sampling covering a wider swath (e.g., few hundred km) than OCO-2, in order to separate individual emission sources (e.g., cities or large power plants) from the background signal.
Overall, the XCO2 anomaly maps provide independent information on the CO2 spatial patterns to support regional modeling studies and a useful tool for understanding anthropogenic emissions, which are currently based on country-level self-reported information. In particular, current national level emission

estimations do not resolve the natural and anthropogenic contributions. Satellite data with high accuracy and good spatio-temporal coverage and resolution can improve these estimations (Bergamaschi et al., 2018)."

> General: it is not clear where results are significant and what the related errors are of the derived anomalies.

We now write: "*…the results are most significant over areas where more data are available throughout the year. The consistency of the spatial features from year to year (or for the same season during different years) is an indicator of the robustness of the results. The FLEXPART simulations also confirm the observed spatial patterns. On the other hand, the error associated with the anomaly is not purely statistical and tends to be more systematic, for example due to persistent wind patterns and uneven geographic distribution of OCO-2 observations. For example, OCO-2 data in the northern middle-latitudes are available predominantly during summer months so the annual maps are likely to be biased towards them."*

> P3 L12, 'latest' will be overtaken in time and should maybe best be removed.

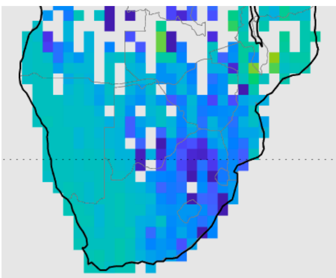
Removed.

> For OCO-2 data, please indicate whether both nadir and glint data are used.

We use both. Now indicated in text.

> P6 L24-25, why do you expect a relation to season in the anomaly of the industrial area of South Africa, especially with the indicated relation to draw down/SIF? You have seen the same in FLEXPART which implies you could pull out the underlying reason.

This is because of the effect of natural ecosystem. Biospheric contributions during DJF from FLEXPART show negative values over the Highveld area as shown in the figure below. This removes part of the positive enhancements due to anthropogenic emissions. We slightly rephrased to clarify.



> The supplement provides details on data density per year in Figure S1, but it would good to also have details on the data density per season.

Done.