

## ***Interactive comment on “Anthropogenic carbon dioxide source areas observed from space: assessment of regional enhancements and trends” by O. Schneising et al.***

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First of all, we would like to thank the reviewer for the helpful comments. Below we give answers and clarifications to all comments made by the referee.

### **General Comments**

*The paper analyses SCIAMACHY XCO<sub>2</sub> data from 2003-2009 over a small selection of urban regions to quantify the associated regional emissions and how they change*

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*with time. They make a strong link between this analysis and the potential of the CarbonSat, which is a mission currently being considered for Earth Explorer 8. The study is interesting but the propaganda undertone of the paper is not useful unless the authors clearly explain how CarbonSat would improve on the results from SCIAMACHY presented here. I don't agree wholeheartedly with all statements made in the paper or some of the analysis but it is useful piece of work that should be considered for ACP. In general this reader would appreciate larger figures and/or larger fonts.*

The added value of CarbonSat is explained more clearly in the revised version. Due to higher accuracy and wide swath imaging with higher spatial resolution (compared to SCIAMACHY) CarbonSat will allow to extend the analysis of large and intense emission regions presented here to more localised and less intense emission sources. It has been shown in the peer-reviewed literature that CarbonSat will be able to independently verify emissions from large individual power plants (Bovensmann et al., 2010; Velazco et al., 2011). Along these lines the current analysis based on satellite data can be seen as a step forward towards CarbonSat's goal of better disentangling natural and anthropogenic carbon emissions. It was not our intention to make propaganda for future missions. We did some rephrasing with the objective of avoiding to create this impression. We have integrated the last sentence of the Introduction into the Conclusions. Please also see the answers to the specific comments for more details.

Figures and/or fonts are larger in the revised versions. In this context it has also to be pointed out that Figures 2-4 were designed for a portrait format and therefore appeared quite small in the landscape ACPD format. All Figures will be easily readable in the revised (portrait) version.

## Specific Comments

*Page 31510, line 17. Comment: if SCIAMACHY was in a geostationary orbit and after subtracting the background variability I suspect you would also see natural variability within the metropolitan area. For instance, in situ work over the Paris metropolitan area has shown that vegetation can impose variability on the city-scale signals. The simple-minded approach described in this paper works only for reasonably homogeneous (i.e. sprawling) urban areas such as Los Angeles. For most cities a more complicated analysis is required.*

It is stressed more clearly in the revised version that the results are obtained for large emitting urban agglomerations/conurbations and not for individual cities. In the case that source and background regions are homogeneously sampled and under the very likely assumption that the natural variability is very similar in both regions, biospheric signals cancel out because of the subtraction of background values from source values. But even in the case of heterogeneous sampling natural variability due to vegetation should be no issue due to the anomaly approach described in the manuscript. For the Paris metropolitan area we still get an enhancement but it is not significant anymore ( $0.5 \pm 0.7$  ppm for the biospheric corrected anomalies using zonally adjacent source and background regions).

*Page 31511, line 21. It would be useful to show the comparison between SCIAMACHY and NOAA in situ data. I appreciate the authors have showed this previously but a simple additional curve to Figure 1 would be appreciated by this reader - both for the CO<sub>2</sub> time series and the CO<sub>2</sub> residual after the growth rate has been removed. How did the authors separate the growth rate from the original time series?*

As the comparability of surface and column-averaged satellite data is limited, in particular when looking at growth rates or seasonal cycle amplitudes, we added a comparison with column-averaged mole fractions of CarbonTracker, which assimilates surface data, to Figure 1. Surface and column-averaged growth rates differ because of age of air and

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variability of the surface growth rate with time; in other words: growth rates of the past "mix in" at high altitudes. The altitude dependent sensitivity of the satellite (averaging kernels) has also to be considered. This is achieved via weighting of height layers when integrating the CarbonTracker profiles and is not possible for surface data.

The temporal increase of CO<sub>2</sub> cannot distort the enhancement estimates because the growth rate is separated due to the anomaly approach described in the manuscript. This is pointed out in the revised version.

*Page 31512, line 5. It would be useful if this reader understood the justification for choosing these sites. Are they the biggest emitters? Are they contrasting regions? Are these the regions with the best agreement between SCIAMACHY and EDGAR?*

As already stated in the manuscript the justification for these sites is that they are the largest emitters in their respective continents. This is also revisited in the conclusions in the revised version.

*Page 31512, line 15. This reader particular abhors vacuous statements such as "as can be seen [insert name of data A] correlates reasonably well with [insert name of data B]..". No, I cannot see the correlation - I can certainly guess what it is but it would clearer if the authors provided these values. There is some agreement in the broad spatial distribution but there are many instances where the emission inventory shows large enhancements associated with urban activity and SCIAMACHY does not observe any significant enhancement. As the authors note this is likely due to atmospheric transport and vertical mixing. To interpret these space-borne data correctly a 3-d atmospheric transport model is required, which I think needs to be fully acknowledged.*

We agree that the wording was a little unfelicitous because "correlate" can be associated with a quantitative number. Actually, we wanted to make a qualitative statement and the sentence is rephrased accordingly in the revised version: "As can be seen, there is reasonable agreement in the broad spatial distribution of SCIAMACHY XCO<sub>2</sub> and EDGAR anthropogenic CO<sub>2</sub> emissions bearing in mind that exactly identical pat-

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terns of retrieved XCO<sub>2</sub> and anthropogenic emissions cannot be expected because of transport and atmospheric mixing. An advanced analysis aiming at smaller and less intense emission regions would require a three-dimensional (3D) atmospheric transport model."

The transport uncertainty (as well as potential emission variability as in the case of China) is reflected in the error estimates of the retrieved enhancements quantifying the interannual variability. The emissions of the considered regions are large enough that the significance of the retrieved enhancement is not harmed and hence visible to the unaided eye.

*Re EDGAR: these emissions are likely to be accurate qualitatively, but have substantial quantitative error for any one year.*

We look at interannual trends of yearly emission enhancements (source - nearby background). Hence, quantitative accuracy of the absolute EDGAR values is not so essential for this analysis. More important is relative (source vs. background region) interannual accuracy for a fixed region which is expected to be satisfied. Potential regional biases in EDGAR (e.g. Europe vs. China) are eliminated to a large extent due to the chosen approach.

*Section 3.2.1: I would like clarification that the GEMS model is being sampled at the time and location of the SCIAMACHY measurements.*

As the wording was obviously ambiguous, the first sentence of Section 3.2.1 is rephrased to make clear that the GEMS model is being sampled at the time and location of the SCIAMACHY measurements.

*Conclusions: The first paragraph is a little strong in my opinion. I don't think based on the work reported that the authors have unequivocally shown that are observing anthropogenic emissions. They have certainly not shown this is generally true. I am uncomfortable that the authors are using this analysis to advertise a completely new*

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*mission that has not been shown to provide information on the spatial scale of individual power plants.*

Due to the performed analysis we are pretty confident that the retrieved signals actually point to anthropogenic CO<sub>2</sub> emissions because the combination of systematic retrieval errors due to aerosols and sampling effects (in combination with natural variability and growth rate) can be excluded as an alternative explanation of the observed variations. Furthermore, we get significant enhancements for the largest emitting conurbations in the expected range and find that the corresponding retrieved enhancement trends are consistent with EDGAR emission enhancement trends. It will be clarified that the results have been obtained for large and intense emitting regions and that CarbonSat can improve on the SCIAMACHY results in terms of "detectable" regions. It has been shown in the peer-reviewed literature (Bovensmann et al., 2010; Velazco et al., 2011) that CarbonSat will be able to provide information on the spatial scale of individual power plants which is stated more explicitly in the introduction of the revised version. In addition, Krings et al., 2011 demonstrated using an airborne passive remote sensing instrument with a measurement technique similar to CarbonSat that retrieved XCO<sub>2</sub> over coal-fired power plants allows quantification of emissions within 10% of the reported values.

The first paragraph of the conclusions is rephrased as follows: "It was shown by analysing SCIAMACHY nadir measurements over the largest emitting conurbations of Europe, America, and Asia that anthropogenic CO<sub>2</sub> emissions can be detected from space and that emission trends might be tracked using satellite observations. Future wide swath imaging satellite instruments with higher spatial resolution, like the candidate Earth Explorer Opportunity Mission CarbonSat, will allow to extend the current analysis of large and intense emission regions to more localised emission sources. In this sense, the presented results can be interpreted as a first step towards the projected capability of future satellite instruments for better disentangling natural and anthropogenic carbon emissions and for monitoring and independent verification of CO<sub>2</sub>

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emissions down to the point-source scale, e.g. power plants."

## References

Krings, T., Gerilowski, K., Buchwitz, M., Reuter, M., Tretner, A., Erzinger, J., Heinze, D., Pflüger, U., Burrows, J. P., and Bovensmann, H.: MAMAP – a new spectrometer system for column-averaged methane and carbon dioxide observations from aircraft: retrieval algorithm and first inversions for point source emission rates, *Atmos. Meas. Tech.*, 4, 1735–1758, doi:10.5194/amt-4-1735-2011, 2011.

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