Response to comments by Referee #2 of EGUsphere-2024-3857

Dear Referee,

Thank you very much for this comprehensive review of our manuscript which helped to improve the manuscript. Please find below our point-by-point responses to your comments. The comments are printed in italics and our responses are shown in upright font.

Kind regards and on behalf of all authors,

Michael Weimer

The authors present the impact of avoiding detector saturation on the precision and sampling frequency of XCO2 retrieved from CO2M data by using the Fast atmospheric traCe gAs retrievaL (FOCAL), and possible CO2M observation scenarios based on simulation experience. I understand that this activity is important to assess and optimize the CO2M observation scenario, and maximize the available observation data from CO2M with requested precision and accuracy. However, some description and assumption are unclear or missing in the text.

*In this study, the sampling duration time for detector is fixed at 308ms. I understand the sampling duration time is composed of the integration time of detector and the time for readout. The times for reading out the signal might be fixed due to the limitation of signal transfer speed between detector response itself and electronical chain, and it is indicated about 37ms in this study. In contrast, the integration time for detector might be able to customize within the allowable time periods which is depended on the character of detector, and this function will lead the optimization of the total performance of instrument. In other words, if the CO2M instrument will be adopted the reduced integration time (234 (=2*117) ms) with the oversampling factor (OSF) =1, it might lead higher SNR and small foot print size than that of OSF=2 (2*(117+37) ms) case, which is proposed by the authors.*

Probably, some limiting conditions on detector operation such as the fixed sampling duration at 308 ms are existed but not clearly described in this manuscript. If these limitations are not existed, the other observation scenario has to be considered, and be proposed. Then, the clarification of limiting conditions on detector operation are important for this study.

Authors' response: The timing of the CO2I/NO2I instrument is driven by the requirements for a) spatial sampling (<= 4 km2) and b) SNR of the spectral radiance measurement. The ACT spatial sampling distance is given by the design of the slit homogenizer (as well as detector size and optical magnification), and is fixed to 1.8 km. This allows for a maximum of ~2.2km spatial sampling distance (SSD) in ALT. At the CO2M orbit this amounts to a sampling time of ~308 ms. We added this explanation to the manuscript. In theory, an optimal sampling time could be derived to avoid saturation, but in practice, it would further reduce the SNR which is already close to the limit and the synchronization of the four spectrometers would be more difficult for a faster sampling time. To clarify this, we added a sentence to line 118 of the preprint: "The value of 308 ms was used to meet all demands within the mission requirements." We agree that one result of this study is that also the sampling time could be reduced to avoid the caveats of an additional read-out, but this requires further studies in the future. Therefore, we added a corresponding paragraph to the conclusions (line 374):

"This study used a fixed sampling period of 308 ms to meet the mission requirements. In principle, this value can be adjusted as well in order to get the optimum between SNR and saturation avoidance. Further investigations in the future could include the reduction of the sampling period instead of increasing the OSF. However, a smaller sampling period would further reduce the SNR and synchronization of the CO2I/NO2I spectrometers might become more difficult with a smaller sampling period."

In addition, the authors mentioned that the operational OSF will be determined during commissioning phase of CO2M mission. I understand that this manuscript is focused on the simulation-based evaluation. However, it is also important to have a plan; how to determine the operational OSF during commissioning phase? Because, the authors mentioned that the retrieval of CO2M will be performed among 3 parties. Then, the clear procedure or plan for determination of OSF might be required.

Authors' response: The planning of the commissioning phase for CO2M is not finalized yet, the critical design review (CDR) is currently in discussion. Part of this study's motivation is that it will contribute to the planning of the commissioning phase. We agree that this has not been outlined in the current manuscript and hence, we added the following sentence to the introduction (line 62) to clarify this: "[…] in order to contribute to the planning of the commissioning phase for CO2M." In addition, we added a final sentence to the conclusions: "These results are intended to be used for the planning of the commissioning phase for CO2M."

Specific comments.

Abstract

Page 1, line 4: coverage. -> "wide" coverage

Authors' response: Corrected.

Page 1, line 8: sampling -> sampling "frequency" or sampling "number".

Authors' response: We changed it to "spatial coverage" instead of sampling.

4. Defining scenarios avoiding detector saturation

Page 8, line 173: What are the criteria for acceptance of constant OSF settings all over the globe? To optimize the parameters, the acceptance levels both global coverage, retrieval precision and accuracy are important. The authors should add the explanation.

Authors' response: The criteria for the satellite mission are defined in the Mission Requirement Document (MRD, ESA, 2020), but they assume the OSF scenario 111. In addition, providing acceptance levels for the coverage (e.g. something like "it should be larger than 95 %") is misleading because sources of greenhouse gases are localized emissions and coverage should be ensured in the areas where CO2 and CH4 are emitted. Therefore, providing specific numbers, which we assume is meant by "acceptance levels" here, is not the right way to do it in this study. In addition, we show later in the manuscript that the retrieval precision with OSF222 is still close to the values of the VEG50 scenario used in the MRD so that the comparability is already provided in the manuscript.

6.2 Impact on coverage

Page 11, line 341: coverage -> spatial coverage.

Authors' response: We replaced both occurrences of "coverage" by "spatial coverage".

Page 12, line 280: In the figure 5, it seems that the middle east countries are indicated as the saturation area. Regarding the Oil & Gas emissions from middle east countries, it might have some impact on emission estimates. In parallel, the authors are focusing on XCO2 on this manuscript. If the authors are considering XCH4, the scenario with OSF111 might be reconsidered. Then, the authors should add the detail explanation for these considerations.

Authors' response: We agree with the referee's statements about the Oil & Gas emissions from the Middle East which would have to be filtered out when using OSF 111. We added the sentence "Note that important emissions from oil and gas industry on the Arabian Peninsula would have to be filtered out when using OSF 111." to the discussion around line 274. On the other hand, we disagree with the referee's statement that OSF111 might be reconsidered when thinking about XCH4 in this region because the issue with saturation is independent of the species so that basically all data would have to be filtered out also for XCH4 in this region. In contradiction to the referee's statement, this is another example that an OSF larger than 1 should be used for CO2M.

6.3 Impact on XCO2

Page 16, Figure 7: The location of legend is not suited and have to move on top or bottom of figures. The current location is hard to find it.

Authors' response: We moved the legend below the figure.

The trends of noise error are almost similar among the OSF's (OSF111, 222, 232, and 333). I understand the most impacted parameters are the multiple number of read-out, digitization and video chain noises. Typically, figure 7(e) is clearly indicated the relationship among the OSF's. However, figure7 (g) and (i) suggests some anomalous relationship in the seasonal variation. Then, the authors should add the explanation what is the course of these anomalies. In addition, figure 7 (a) suggests that the setting of OSF222 creates the minimum noise error condition during winter season (October, November, December). In this case, how to conclude the optimization of OSF for CO2M mission? So, the authors also should add the explanation for these conditions.

Authors' response: The anomalies come from the different number of data filtered due to saturation. As can be seen in the figure, the anomalies are within the tropical regions between 40°S and 40°N where most of the deserts on the Earth's surface are located, see also panels (h) and (j) showing the number of data in these latitude bands. As the deserts include most of the saturated spectra, filtered out during pre-processing, and they have a large signal if they are not filtered out their noise error will be smaller than the average. Therefore, the median noise error for OSF 111 is increased when filtering for saturation. We added the following sentence to line 315 of the manuscript: "As the SNR is connected to the noise error (see Fig. 4) and the signal over deserts is usually larger than the average, the median noise error increases when the saturated spectra of desert regions are filtered out, which explains the anomalies in the noise error globally and in the near-tropical latitude bands (panels a, g and i)."

7. Summary and Conclusions

Page 19, line 383: How to optimize the OSF during commissioning phase? The authors conclude that the scenarios 111 and 222 seems to be favorable for CO2M in the future with the FOCAL. In this study, the conclusion is based on the simulated one-year subset of radiance data, and not considered the retrieval results from Fusional-P-UOL-FP and RemoTAP. To optimizing the operational scenarios during the commission phase of CO2M, the authors also have to consider the realistic procedure how to determine the OSF? The authors should add the explanation.

Authors' response: It is clear that all parameters have to be considered, but the planning of the commissioning phase is not finalized yet. This study provides the planning of the commissioning phase with parameters to be considered, which is actually the motivation of this study. That is why we added clarifications to introduction and conclusions as stated in our response to your major comment above.