We are grateful to the referee for these positive comments and suggestions. We are replying to the comments and questions in red, between the referee's text.

The paper "Synthetic mapping of XCO2 retrieval performance from shortwave infrared measurements: impact of spectral resolution, signal-to-noise ratio and spectral band selection" provides detailed analysis of the characteristics of CO2 measurements with SWIR spectrometers with a range of resolutions, signal to noise characteristics, and spectral bands. Characteristics of actual spectrometer designs (CO2M, MicroCarb, NanoSat), as well as a large set of hypothetical instrument configurations are considered.

The paper reports on detailed analysis of the XCO2 precision, the degrees of freedom for CO2, the vertical sensitivity, the sensitivity for and possible interference due to parameters such as temperature, water vapor, albedo, and aerosols. A wide range of scenarios (or situations) are explored, where surface reflectance and solar geometry are systematically changed.

Overall, this paper is very well constructed. The experiments and assessments are carefully structured and the key findings are clearly described. The graphics are effective, the completeness of the analysis is impressive, and the writing is clear.

General review comments:

Overall, this is an impressive and comprehensive piece of work. It can serve as a reference for instrument developers as they seek to optimize performance and evaluate the trade space of resolution, signal to noise, and band pass. The methodology is clearly described, including the input data and calculations that are performed.

One weakness I find in this paper is the treatment and description of the CO2M instrument. There should be language included to clarify that this work is assessing just the spectrometer element of CO2M, which will also integrate a multi-angle polarimeter. The assessment of XCO2 precision and error related to aerosols is a correct analysis for the CO2M spectrometer alone, but not the planned CO2M mission. I would suggest that this point is made clear at the beginning, and perhaps they use the phrase CO2M spectrometer in the paper.

We agree with the referee that this is indeed a very important point. It was already discussed in the original manuscript when exploring aerosol sensitivities for CO2M, near the article end: "These values are well below the 0.5 ppm systematic error requirement (Meijer, 2020), and are expected to be even more reduced by using the aerosol observations provided by the Multi-Angle Polarimeter that will fly along CO2M spectrometers (e.g. Rusli et al., 2021)."

As MAP results can also help to have reduced prior uncertainty on aerosol parameters, and thus also impact precision results, we agree with the referee that this should point should have also been discussed earlier in the paper. We added some extra comments when presenting CO2M to discuss this point right from the start.

Lines 180-184	In this work, we use the **spectrometer** measurement characteristics presented in Table 3 to model the CO_2M concept. **Besides the spectrometer, the CO_2M mission will also include a Multi-Angle Polarimeter, which is an instrument dedicated to the observation of aerosols. Its results are expected to help better constrain their**

	interfering effect on X_{CO_2} retrievals, and improve their precision and accuracy (Rusli et al., 2021). Here, we only study the CO_2M spectrometer alone, thus the results that we obtain do not reflect the comprehensive theoretical CO_2M mission performance.

To gain confidence in the methodology, it would be useful for the authors to point out where OCO-2 and GOSAT(-2) are in these SNR/resolution plots, and to compare to published results for precision, DOF, etc. I suggest this because sources of error such as spectroscopic mischaracterization or errors in instrument characterization are not well captured in the analysis presented here, yet may be important contributors to error. The mismatch for actual missions may provide some insight into the errors not captured in this analysis.

This comment is identical to the first one made by referee #3, thus we reproduce below a common answer to both comments.

The point raised here by the referee is very relevant. In the revised manuscript, we have included OCO-2 results in Figures 3, 4, 5 and 6, and in Supplementary Figures S4, S5, S7-10, S12-17,.

We also introduce how we model OCO-2 observations in a Subsection 2.1.

Line 148 - 154	**The Orbiting Carbon Observatory-2 (OCO-2) has been providing X_{CO_2} observations from SWIR measurements for close to a decade (Taylor et al., 2023). We include this instrument in order to assess how the synthetic results obtained here relate to results obtained from real data. We model OCO-2 observations relying on instrument functions and noise models provided in OCO-2 L1b Science and Standard L2 products of Atmospheric Carbon Observation from Space algorithm version 8 (ACOS, O'Dell et al., 2018). These files are not from the latest v10 version of OCO-2 data, but the v8 to v10 major reprocessing did not include significant changes on instrument parameters (Taylor et al., 2023), so we assess that our input data are acceptable for this synthetic study.**

We finally discuss the obtained XCO2 precision for OCO-2 against the one reported in OCO-2 Standard L2 product in Subsection 5.1:

Line 643 - 653	**First, OCO-2 shows a noise-only related precision of 0.32 ppm corresponding to DOFs for CO_2-related parameters of 1.97. The OCO-2 results that we obtain are overall consistent with ACOS results for soundings with close band-wise albedo values (see Supplementary Figure S6). Besides, land nadir OCO-2 X_{CO_2} retrievals show an overall 0.77 ppm standard deviation compared to the Total Carbon Column Observing Network (TCCON) validation reference (Taylor et al., 2023). This difference with respect to the theoretical uncertainty computed from Optimal Estimation stems from all the forward and inverse modelling errors that are not accounted for in the retrieval scheme. Thus,**

	this illustrates that the results provided in this study are a lower bound to the actual precisions that these upcoming concepts will have.

Supplementary Figure S6 (reproduced here in Figure R2.1) provides the XCO2 uncertainty due to noise (field 'xco2_uncert_noise' in L2StdND oco2 files) and CO2-related DOFs. For each albedo model considered in this study, we explored the year 2016 ACOS v8 L2 data downloaded for the work performed in Dogniaux et al. (2021) and averaged precision and DOFs results for soundings that match our albedo models within ±0.05. The error-bars range from the 10^{th} to the 90^{th} percentile of each distribution. Our OCO-2 results have been linearly interpolated to match the average OCO-2 Solar Zenith Angle in the considered ACOS data, and the error bar range from the minimum to the maximum values obtained in our synthetic survey.

We can notice that we obtain DOFs that are quite close to ACOS (a little higher because we fit less geophysical parameters in our state vector), and produce noise-related precision results that are close or lower compared to ACOS. Besides, case-to-case differences are also overall consistent between our results and ACOS (SOL and VEG cases show lower DOFs and higher uncertainties than DES cases). However, as many aspects differ in aerosol models, state vector composition, radiance and noise levels, etc, between the OCO-2 soundings that we average here and our 12 explored observational situations, we refrain from comparing further our results and ACOS', and assess that we find an overall agreement that seems acceptable given the differences between the synthetic evaluation performed here, and the ACOS inverse scheme.

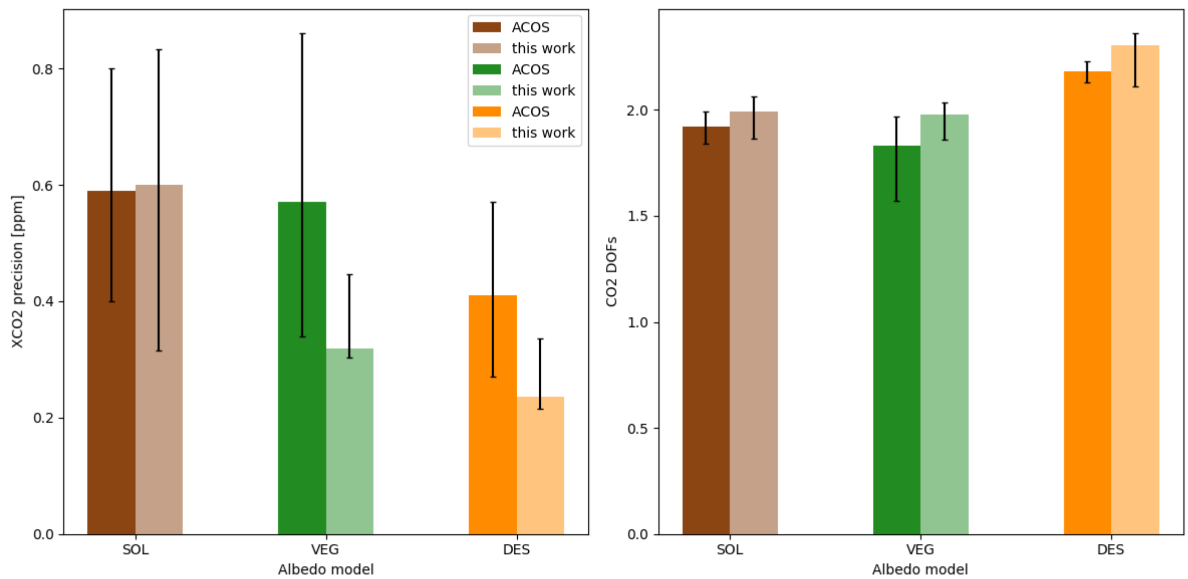

Figure R2.1. XCO2 uncertainty due to noise and CO2-related DOFs from ACOS v8 L2 data (full colors) and from our synthetic study (light colors). For each albedo model considered in this study, we explored the year 2016 ACOS v8 L2 data downloaded for the work performed in Dogniaux et al. (2021). We averaged the precision field 'xco2_uncert_noise' (in L2StdND oco2 files) and DOFs results for soundings that match our albedo models within ±0.05. The error-bars range from the 10^{th} to the 90^{th} percentile of each distribution. Our OCO-2 results have been linearly interpolated to match the average OCO-2 Solar Zenith Angle in the *considered ACOS data for each albedo model, and the error bar range from the minimum to the maximum values obtained in our synthetic survey.*

Specific comments:

1) Lines 210 – use soot and minerals as their aerosols – what justifies these choices? For many parts of the world, these are not representative.

These two models were chosen as possible aerosol types of fine and coarse mode that may pollute the European continent: soot representing here urban pollution and minerals the minerals transported from the Sahara Desert from spring to fall (Papayannis et al, 2008). We do agree with the referee that many different types of aerosols could have been explored, but including a wider range of atmospheric conditions is out of the scope of this study.

We propose to underline this choice better presenting the atmospheric and observational situations explored in this study.

Lines 242-243	**As this study focuses on the impact of instrument design parameters on X_{CO_2} retrieval performance, we purposefully limit the number of atmospheric conditions that we include.** We consider 12 atmospheric…

Lines 264 -266	**To mimic possible pollution over the European continent we include** fine-mode aerosols, representative of soot, between 0 and 2 km of altitude, and coarse mode aerosols, representative of minerals, between 2 and 4 km of altitude (**this choice is supported by transported desert dust layers over Europe described by (Papayannis et al., 2008).**

How do the absorption and scattering characteristics impact the results?

Here, the optical properties are supposed to be perfectly known, consequently this parameter has not been studied. We do agree with the referee that exploring different aerosol types spanning different optical properties would be valuable. However, exploring a wider range of atmospheric conditions is out of the scope of this study, as doing so would tend towards an actual comprehensive OSSE.

We propose to add a discussion element when presenting the aerosol model repeating that their optical properties are fixed, and some additional conclusion elements mentioning as further work the exploration of a wider variety of atmospheric conditions.

Lines 842 - 849	**Given its scope focused on exploring the impact of concept design parameters on X_{CO_2} retrieval performance, this study could not include all the dimensions of a comprehensive mission performance assessment. For example, the accuracy of X_{CO_2}**

	retrieval has not been studied, and a greater variability of possible atmospheric conditions (different aerosol types, layers, contents, etc., different thermodynamical profiles and CO_2 concentration vertical profiles) could be encompassed, as is usually performed in comprehensive Observing System Simulation Experiment. Besides, this work could not also obviously explore the whole extent of possible design parameters (e.g. band-wise variations of spectral sampling ratios, varying wavelength interval for spectral bands, combination of different instruments, etc.) that impact X_{CO_2} retrieval performance, and its implication for anthropogenic plume imaging. These limitations warrant further studies.

2) The paragraph that starts at line 296 discusses Figure 3. The authors use the word "break". I think the changes in slope of these lines is not all that significant, so break is not a good choice of phrasing. I would suggest a phrase like "change of slope"

We changed the formulation, thank you very much. We replaced "breaks" by "change" in different places of the revised manuscript.

3) Sections 4.1 and 4.2 could have a short introductory paragraph to introduce the structure of the subsections that follow.

We added such short introductory paragraphs.

Lines 352-354	**This subsection explores the combined impact of spectral resolution and signal-to-noise ratio on X_{CO_2} retrieval performance. First, we discuss how X_{CO_2} precision and CO_2-related degrees of freedom evolve with spectral resolution and signal-to-noise ratio, and then we examine X_{CO_2} vertical sensitivities.**

Lines 455-458	**This subsection explores the combined impact of spectral resolution and band selection on X_{CO_2} retrieval performance. First, we discuss how X_{CO_2} precision and CO_2 and non-CO_2 related degrees of freedom evolve with spectral resolution and band selection, and then we examine X_{CO_2} vertical sensitivities. Finally, we explore X_{CO_2} sensitivities to a priori misknowledge of interfering geophysical variables, with an eventual focus on aerosol-related parameters.**

4) Line 330: The starting sentence of this section (4.2.1) is nearly the same text as is used to start section 4.1.1

- On line 270

270 For the atmospheric situation VEG-50o, Figure 3 shows the XCO2 precision (or random error and degrees of freedom (hereafter DOFs) as a function of both the resolving power $\lambda/\Delta\lambda$

and the signal-to-noise ratio (SNR) for CVAR, and for the exact CO2M, MicroCarb and NanoCarb concepts (results for exactly-defined concepts are discussed in Sect. 5)

- Line 330

For the atmospheric situation VEG-50o[…], Figure 5 shows the XCO2 precision and DOFs as a function of both the resolving power $\lambda/\Delta\lambda$ and spectral band selection for CVAR (with SNR fixed at its reference value), and for the exact CO2M, MicroCarb and NanoCarb concepts (results for exactly-defined concepts are discussed in Sect. 5).

- To address this, Section 4.2.1 could have a sentence to first introduce the focus of the analysis. Perhaps "In this section we assess the impacts of changing the spectral bands". (and section 4.1.1 could be introduced with " Here we look at SNR impacts on precisions and DOF.

We added two small sentences as advised at the beginning of each section.

Line 359	**Here, we assess the impact of varying spectral resolution and signal-to-noise ratio.** For the atmospheric situation VEG-50°, Figure 3 shows the X_{CO_2} precision (or random error) and degrees…

Line 460	**Here, we assess the impact of varying the spectral resolution and band selection.** For the atmospheric situation VEG-50° (results for other situations are given in the Supplements), Figure 5 shows the X_{CO_2} precision and DOFs as a function of both

5) Lines 382 and following: I find this language to be very convoluted, and suggest a rewrite.

Currently "While methodologies are hardly comparable (because this study is only based on synthetic simulations), both works agree that a sharp change in how XCO2 precision evolves with resolving power is to be expected around $\lambda/\Delta\lambda$ = 1000 – 2000, when solely using the 1.6 or 2.05 µm CO2 bands"

Suggest:

"While methodologies are hardly comparable (because this study is only based on synthetic simulations), both works agree that the XCO2 precision and resolving power relationship has a change of characteristic around $\lambda/\Delta\lambda$ = 1000 – 2000, when solely using the 1.6 or 2.05 µm CO2 bands"

We followed the referee's suggestions to reformulate this sentence (New text lines 521-524).

6) Figure 11 – I can not differentiate the colors of MicroCarb B1234 and NanoCarb comp.

We change the linestyle of NanoCarb comb to 'dotted' to help better differentiate them.

7) Line 608 – The phrase “more easily gained” implies that we just need to make higher SNR instruments and we can easily get better precision. But this paper just studies the sensitivities. I would suggest rephrasing to “Overall, precision is more sensitive to SNR improvements than spectral resolution improvements.”

We followed the referee’s advice in the revised manuscript. In addition, comments from Referee #1 made us revise this very general statement that is not true for all magnitudes of SNR and resolving power changes.

Lines 392-394	Hence, it appears that X_{CO_2} precision **is more sensitive to SNR** improvements rather than through resolving power improvements**, for large improvements of two orders of magnitude centred on CO_2M instrument characteristics.**

Lines 793-794	Overall, **for these large changes of about two orders of magnitude**, precision is **more sensitive to** SNR improvement than to spectral resolution improvements.

Editorial comments:

Line 525 – the word Temperature is capitalized mid-sentence.

We fixed this mistake, thank you very much.

Lines 673, 674, 688, 716, 719 and 720 (and maybe others) – formatting issues in the references – looks like latex formats not properly converted???

Indeed, the Mendely Microsoft Word plugin gave us a hard time building the reference from bibtex files, and so does the Zotero plugin as well.

We fixed all the LaTeX-related typos by hand in the revised manuscript.

Citation: https://doi.org/10.5194/amt-2023-233-RC2

References

Papayannis, A., et al. (2008), Systematic lidar observations of Saharan dust over Europe in the frame of EARLINET (2000–2002), J. Geophys. Res., 113, D10204, doi:10.1029/2007JD009028.

Dogniaux, M., Crevoisier, C., Armante, R., Capelle, V., Delahaye, T., Cassé, V., De Mazière, M., Deutscher, N. M., Feist, D. G., Garcia, O. E., Griffith, D. W. T., Hase, F., Iraci, L. T., Kivi, R., Morino, I., Notholt, J., Pollard, D. F., Roehl, C. M., Shiomi, K., Strong, K., Té, Y., Velazco, V. A., and Warneke, T.: The Adaptable 4A Inversion (5AI): description and first X_{CO2} retrievals from Orbiting Carbon Observatory-2 (OCO-2) observations, Atmos. Meas. Tech., 14, 4689–4706, https://doi.org/10.5194/amt-14-4689-2021, 2021.