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Interactive comment on "Spectral Sizing of a Coarse Spectral Resolution Satellite Sensor for XCO_2" *by* Jonas Simon Wilzewski et al.

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Reply to interactive comment by anonymous reviewer #1

We thank the reviewer for the helpful comments to our manuscript. Below we repeat the reviewer's questions in **bold** font and subsequently provide our responses.

1. It is unclear to me how column mean dry air mole fractions of CO2 are obtained in a retrieval without NIR band, i.e. in a retrieval where no O2 column is estimated. Where is the information on O2 taken from? From surface pressures from a weather prediction model? How does that add to the overall uncertainty? Isn't the retrieval very sensitive to topographic variations and thus to the

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Discussion paper

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pointing accuracy of the instrument in this case?

Column averaged dry air mole fractions of CO_2, XCO_2, are calculated by deviding the retrieved CO2 concentrations by the airmass below the satellite. In our work, the airmass is determined from a global digital elevation model (NASA's Shuttle Radar Tomography Mission – SRTM) together with surface pressure reanalyses from ECMWF (ERA Interim). This is the standard way how our native RemoTeC algorithm works for trace gas retrievals from the GOSAT, OCO-2 and TROPOMI satellite instruments.

The point raised in your comment about pointing accuracy is very important. Naturally, if our proposed instrument was pointed towards a target site on a terrain with a great slope, pointing errors would be translated into elevation errors/XCO_2 errors (20 m of elevation error would result in roughly 1 ppm of XCO_2 error). Thus, errors in the calculation of the airmass are part of the overall uncertainty found in our analysis. But, these error contributions are equal for the native and reduced-resolution retrievals because the calculation of airmass is the same. In fact, not shown in the paper, we tried to refine our analysis by looking at localized signals above the urban area of Los Angeles. There, we found that uncertainties in GOSAT's pointing can induce significant errors relatated to the airmass calculation.

To clarify how airmass is obtained, we added the following on page 7, line 23 – 28: "For both, native GOSAT and degraded SWIR configurations, airmass information is derived from ECMWF surface pressure reanalyses (ERA-Interim) and topographic data from the Shuttle Radar Tomography Mission (SRTM). For each sounding, we use ECMWF and SRTM data to calculate the ground-pixel average surface pressure and the corresponding dry airmass.. This is the standard operation procedure for RemoTeC trace gas retrievals from the GOSAT, OCO-2 and TROPOMI satellite instruments. Errors in the calculation of the airmass can be caused by erroneous satellite pointing; these errors are part of the overall errors reported for the TCCON validation sites (section 3)."

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2. A problem not really addressed in the study is the fact that coarser spectral resolution instruments tend to have larger uncertainties in the spectral calibration. The retrieval can account for spectral shifts, but this is more difficult in case of coarsely resolved spectra. What were the assumptions regarding spectral calibration uncertainties and how would that affect the conclusions?

There were no assumptions regarding spectral calibration uncertainties in this study. Spectral shifts are free parameters in our retrieval for both, the native and the reduced resolution setups. We start with the standard spectral calibration provided in the GOSAT L1B data files. Then, the retrievals shift the simulated observations to minimize the least-squares difference to the observations. Any errors caused by interferences of adjusting the spectral shifts and fitting XCO_2 are contributors to the errors that we discuss in the paper. However, we have no indication (e.g. particularly large uncertainties of the spectral shift parameters) that spectral shifting is a large error contribution.

3. Only quality-screened cloud-free GOSAT spectra were used in the analysis. How much does that screening depend on the information in the NIR and SWIR channels? Or in other words, how much more difficult would quality/cloud screening be for an instrument with a single SWIR channel? This seems important to me, since only a small proportion of pixels usually survive the strict quality flagging required for satellite CO2 retrievals.

The question of quality screening has not been addressed in this study. Unfortunately, we cannot afford the computational costs to reprocess the entire GOSAT dataset (including all the cloudy data) of the years 2009 to 2016 that we used in the study. Thus, we cannot give a quantitative reply to this remark, but we argue that while cloud detection would certainly be more challenging with a coarse resolution 1-Band

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configuration, the SWIR-2 spectral range offers the possibility to construct a decent cloud filter. To this end, one could make use of the two CO_2 bands in this window, which have the advantage of having very different optical depths. XCO_2 retrievals from either band should then be consistent in cloud-free scenes and different in complicated scenes. Yet, to assess this screening procedure, a follow up study is necessary.

We now mention in the paper that we did not carry out a cloud filtering exercise on page 5, line 8: “Due to computational costs, we restrict our analysis to cloud-free, quality screened soundings over land as identified by the native GOSAT retrievals of the RemoTeC algorithm...".

Also, we added a discussion of the SWIR cloud filter option in the discussion (page 18, line 4 – 8): “Additionally, the SWIR-2 seems better suited for the construction of a cloud filter, because its CO_2 bands have very different optical depths. Similar to the cloud filter currently in use for GOSAT measurements, one could retrieve XCO_2 from the two SWIR-2 bands individually and filter for discrepancies. This scheme should be tested in the future."

Since the main application of the sensor will be point-source detection and quantification, a future study should focus on local rather than global scales as done here. The recent study of Cusworth et al. (2019; https://doi.org/10.5194/amt-2019-202), for example, shows that local plume detection can be significantly affected by retrieval errors which are correlated with surface reflectance. The spectral resolution of the instrument proposed here may be high enough to mitigate such problems, but this aspect should receive more attention in a future study.

Thank you for pointing out the study by Cusworth et al., which we now cite in the discussion (page 17, line 30): “Surface reflectance has been shown to be a central driver in methane retrieval precision by Cusworth et al. (2019)". We also agree that

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local scale phenomena related to surface reflectance and plume detection need to be investigated further in coming studies.

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