Responses to reviewers: "The GHGSat-D imaging spectrometer"

We thank the reviewers for their comments and suggestions, which we address below. Reviewer comments are in *italics* and our responses are in normal font style.

Anonymous Referee #1

1) *Scattering at aerosol is neglected in the atmospheric model motivated by e.g. the work of Houweling et al., 2005, which treats total column CO2 measurements. I think that the finding of a decreased aerosol induced error for narrow layers close to Earth's surface cannot directly be transferred to the presented study of localised and strong emission plumes with much higher spatial resolution. The presented methane emission measurements show a different geometry with very high concentrations at low altitude. For low altitude aerosol and particularly for co-emitted aerosol (as mentioned in the manuscript, l.4,p.8), induced light path changes are likely to have a stronger impact on the vertical column density quantification. And thus, the influence of aerosol on the flux determination can become relevant.*

   We agree with the reviewer that the case studied by (Houweling et al., 2005) is similar, but not exactly the same, to the case of a localized aerosol plume co-emitted with methane. Therefore, we have included a citation to a recent study (Huang et al., 2020) showing that neglecting aerosols leads to approximately 5% error for cases of a co-emitted aerosol plume with significant aerosol optical depth, an error level that is small compared to other errors that afflict our measurement (8-25%, as reported in Section 5). We have also included a citation of a AVIRIS methane retrieval paper (Thorpe et al., 2014) which justifies neglecting aerosol scattering in the forward model on similar grounds.

2) *The authors mention the absorption of CO2 and water vapour in the chosen wavelength window (p4, l13-14). If CO2 and water vapour amount are fixed parameters in the model inversion, their cross interferences need to be quantified in order to exclude any significant influence on the methane measurement. The influence of local gradients (e.g. emission plumes or co-emission) of these gases, as well as aerosol induced light path variations (see above) should be quantified (e.g. by using the introduced model).*

   The methane, CO_2, and water vapour are all retrieved parameters. We have revised the manuscript in Sections 4.4 and 4.5 in order to make this fact more clear.

3) *Figure. 3 (a) indicates that within the pass band of the order sorting filter there are three FP transmission fringes. This should be mentioned/motivated in the instrument description. Selecting 3 transmission peaks triples the light throughput compared to a measurement with a single peak and therefore enhances the SNR by sqrt(3). On the other hand, a dilution of the absorption signal of strong absorption lines is expected, reducing the SNR by up to a factor of 3. For the FP's free spectral range correlating with the spectral separation of strong periodic absorption structures (e.g. as in Vargas-Rodriguez and Rutt, 2009 or Kuhn et al., 2019) the sensitivity, selectivity and the SNR would be increased by using several FP transmission peaks. The instrument description does not mention if such a correlation is used.*

We include the motivation for the specific choice of spectral bandpass and number of F-P modes in Section 2.2..

The reviewer mentions interesting papers in which periodic structure between rovibrational transitions and FP transmission modes are exploited to enhance a combination of the signal and fractional absorption. GHGSat-D does not make use of this correlation.

4) *How does the measurement error/sensitivity vary across the imaging FOV? In Fig. C2 4 (a)-(d) the rings of equal FP transmission are faintly visible. A pixel located in the centre of the detector will see a different FP interferogram compared to a pixel close to the detector edge. I.e. the progression of the signal as shown in Fig. 4 (e) is dependent on the location of a pixel on the detector. A slight tilt of the FP in along track direction would increase the radii of the FP rings within the FOV. This could have the advantage of a better coverage of the whole FOV with similar FP interferograms and also it would increase the range of FP tuning (~cos(alpha)) per pixel. Thereby the spectral information of the measurement could be further enhanced and areas on the detector with low dynamics in spectral FP changes (e.g. the centre area of the detector) were avoided.*

   The reviewer is right to point out that the measurement sensitivity varies across the imaging FOV. We have included additional discussion to Section 5 to note this fact.

5) *Fig. 3 (c) shows the 'instrument signal' as a function of the radius. Here it would be illustrative to show the differential instrument signal between a typical methane plume and a plume free region. Thereby the sensitivity of the method in terms of measured optical depth per methane amount would become more clear. Also the influence of typical CO2 and water vapour absorption gradients could be illustrated that way.*

   The instrument signal in Figure 3(c) shows the response to the nominal background concentration levels of methane, CO2, and water vapour at a representative solar zenith angle and target elevation. We have revised the manuscript to include these exact values in the caption to Figure 3. Since the majority of the absorption features in instrument signal are due to methane, it is now possible to infer the sensitivity of the signal to an amount of methane.

References:

Houweling, S., Hartmann, W., Aben, I., Schrijver, H., Skidmore, J., Roelofs, G.-J. and Breon, F.-M.: Evidence of systematic errors in SCIAMACHY-observed CO 2 due to aerosols, Atmos. Chem. Phys., 5(11), 3003–3013, 2005.

Huang, Y., Natraj, V., Zeng, Z. and Yung, Y. L.: Quantifying the impact of aerosol scattering on the retrieval of methane from airborne remote sensing measurements, Atmos. Meas. Tech. Discuss., 1–28, 2020.

Thorpe, A. K., Frankenberg, C. and Roberts, D. A.: Retrieval techniques for airborne imaging of methane concentrations using high spatial and moderate spectral resolution: application to AVIRIS, Atmos. Meas. Tech., 7(2), 491–506, 2014.