# Author comments on the manuscript “Sentinel-5 SWIR Detector Persistence on Trace Gas Retrievals”, reviewer 2

We thank the referee for the positive assessment of the manuscript and for the constructive comments. We appreciate the recognition of the overall clarity of the methods and results, and we address the points requiring further explanation in detail below. The original comments are reproduced in *bold*, followed by our replies. Page, line, and figure numbers refer to the original manuscript unless stated otherwise.

**General Comments:**

1. **The methodology section should make clear how instrument noise is handled. It seems that all simulations of spectra do not consider instrument noise, but this is not clearly written in the text. This may be valid because the persistence effect probably results in more systematic errors, but noise will affect the signal levels on the detector in different ways for high and low intensities, which may possibly influence the results. The same applies for e.g. dark signals, which are also not mentioned (and probably not considered). The consideration (or not) of noise and darks should be stated in the text and a possible impact on the results should be discussed.**

   Adjusted

   Instrument noise was not explicitly added to the simulated spectra used in this study, as the analysis was designed to isolate the systematic retrieval errors caused by detector persistence under otherwise controlled conditions. The retrieval nevertheless accounts for the expected instrument noise through signal-dependent noise estimates, which determine the relative weighting of the spectral measurements. Assuming that errors remain sufficiently small for linear error propagation to apply, persistence-induced biases can be treated separately from random noise contributions. In this framework, noise would primarily increase the variability of the retrieval results, while the systematic effects of persistence remain unchanged.

   We added on P4, L124 the following line:
   “Instrument noise is not explicitly added to the simulated spectra, as the aim is to isolate persistence-induced biases. This simplification neglects signal-dependent noise, which contributes a statistical component to the mission error budget. The magnitude of this component is specified in the mission requirements *(European Space Agency (ESA), 2020a)*.”

2. **The results presented in the paper are mainly based on the simulation of three different regions for a constant geometry. How representative are these regions (and geometry) for the global data provide by Sentinel-5? How many data would be affected, and how many would be filtered out on a global scale? This would give more insight on how relevant the effect and possible correction would be.**

   Partially adjusted

   The simulations presented in this study are not intended to provide globally representative statistics, but rather to assess the sensitivity of the retrievals to persistence effects under controlled conditions. The selected regions were designed to span a range of surface albedo values and contrasts, including extreme configurations where persistence effects are expected to be most pronounced, with large and heterogenous albedo transitions.
   A constant viewing and illumination geometry was assumed in order to isolate the effect of persistence and avoid introducing additional variability related to changing observation conditions. While geometry influences absolute radiance levels, the persistence effect primarily depends on relative changes in radiance across the scene, so the qualitative behavior described here is expected to be broadly representative.
   Because persistence-induced biases depend strongly on local scene characteristics (e.g. albedo contrast and spatial transitions), and since the simulated scenes are not sampled from a global distribution, it is

not possible to derive meaningful global statistics (e.g. fraction of affected data) from this setup. Providing such estimates based on a limited set of constructed scenarios could therefore be misleading.

Moreover, a purely global perspective does not fully capture the relevance of persistence-induced errors, as it overlooks their impact at the local scale. Persistence-induced biases occurring in regions with strong radiance gradients can directly affect the estimation of localized sources, even if they represent only a small fraction of the global data. The objective of this study is therefore not to quantify the global occurrence of persistence effects, but to investigate their magnitude and behavior under representative and extreme conditions. Instead, the results should be interpreted as indicative of potential local impacts, particularly in regions with strong radiance gradients such as coastal zones or inland water bodies.

We changed p8, L222 the line:
"We assess the spatial variability of the resulting persistence bias, its dependence on surface albedo, and the effect of simple filtering strategies on the overall bias statistics."
To:
"We assess the spatial variability of the resulting persistence bias for each scene, its dependence on surface albedo, and the effect of simple filtering strategies on the overall bias statistics. The selected regions are not intended to be globally representative, but rather to span a range of surface albedo conditions and contrasts; the results should therefore be interpreted as indicative of local effects rather than global statistics."

**Specific Comments:**

3. **p. 2, l. 58–59: 'MicroCarb and CO2M adopt more stringent accuracy requirements for XCO2 (of 0.4 ppm...)' Is there a reference for these accuracy requirement values?**

   Adjusted

   Changed in P2, L57:
   "For context, dedicated $CO_2$ missions such as MicroCarb and CO2M adopt more stringent accuracy requirements for $XCO_2$ (of 0.4 ppm, corresponding to approximately 0.1 %), which makes it particularly relevant to assess persistence effects on $CO_2$ the present analysis."
   To:
   "For context, dedicated $CO_2$ missions such as MicroCarb and CO2M adopt more stringent accuracy requirements for $XCO_2$, on the order of ~0.1 % or below (ESA, 2020b; ESA, 2024), highlighting the importance of assessing persistence effects on $CO_2$ in the present analysis."

4. **p. 4, l. 115: Please describe which spectroscopic data, especially which absorption cross sections, have been used. Are these the same as used in the operational retrievals?**

   Adjusted

   We have clarified the spectroscopic setup used in the simulations. Absorption cross-sections are computed line-by-line using spectroscopic parameters from the HITRAN database (Rothman et al., 2009), together with additional spectroscopic data from Tran et al. (2006) and Scheepmaker et al. (2013). This setup is consistent with the RemoTeC retrieval framework. As the Sentinel-5 retrieval algorithms are still under development, the final operational spectroscopic configuration has not yet been finalized.

   We changed on P4, L114 the following line:
   "The accurate modeling of absorption by molecules relies on spectroscopic databases, which provide the absorption cross-section of the target absorber CH4 as well as of the interfering gases CO, CO2, H2O and O2 (Tran et al., 2006; Rothman et al., 2009; Scheepmaker et al., 2013)."
   To:
   "Molecular absorption is modeled using spectroscopic parameters from the HITRAN database (Rothman et al., 2009), with additional spectroscopic data for methane and related species from Tran et al. (2006) and Scheepmaker et al. (2013). Line-by-line absorption cross-sections are computed for $CH_4$ and the interfering gases CO, $CO_2$, $H_2O$, and $O_2$, consistent with the spectroscopic setup used in the RemoTeC retrieval framework."

5. **p. 5, retrieval section: Which a-priori values have been used? Are they equal to the true values? What about assumed a-priori uncertainties? Is this in line with the operational processing? Please explain.**

   Clarified

   For trace gases and, where applicable, aerosols, the a priori is set equal to the true state used to generate the synthetic spectra, while surface albedo is retrieved with a scene-independent a priori. The same albedo parameterization as in the forward simulations is adopted in the retrieval. This setup is largely consistent with the operational processing in terms of the retrieval configuration, but differs in the choice of a priori state. In operational products, the a priori is derived from external information and is generally not equal to the true atmospheric state Here, setting the a priori equal to the true state is a deliberate simplification to minimize a priori-related errors and isolate the impact of persistence. This ensures that, in the absence of persistence, the retrieval is consistent with the true state, so that differences between perturbed and unperturbed retrievals can be attributed directly to persistence-induced effects. We have clarified this point in the manuscript.

   Added on P7, L185 the following line, where we have also addressed comment from referee 1:
   "The same albedo parameterization as in the forward simulations is adopted in the retrieval. For trace gases and, where applicable, aerosols, the a priori is set equal to the true state used to generate the synthetic spectra, and no explicit a priori uncertainties are imposed. This configuration provides a consistent reference case, so that the dominant differences between perturbed and unperturbed retrievals can be attributed to the persistence effect."

6. **p. 9, l 256: 'we applied an a posteriori land-fraction filter to remove pixels partially or fully over water.' Does this mean that Sentinel-5 will perform retrievals over water/ocean (maybe in glint mode)? If this is the case, a lot of data would possibly be filtered out, which is not considered in the numbers derived from the simulations. Please explain.**

   The applied land-fraction filter is intended as a simple a posteriori mitigation approach to identify and remove pixels most affected by strong albedo transitions, particularly at land–water interfaces. It is not intended to exclude all water or ocean observations. Retrievals over water, for example in sunglint geometry, are routinely performed (e.g. for TROPOMI methane retrievals; Lorente, 2022) and remain an important component of the observing strategy. The purpose of the filter in this study is to demonstrate that persistence-induced outliers can be reduced using a simple scene-based criterion. At the same time, we note that sunglint scenes may themselves be affected by persistence due to strong radiance contrasts, and therefore also require further investigation. In an operational context, filtering approaches would need to be optimized to balance data coverage and data quality, and refined to retain valid observations—including glint—while selectively removing the most problematic pixels. We have clarified this point in the manuscript.

   Added on P9, L269:
   "At the same time, observations over water (e.g. sunglint) remain important and may also be affected by persistence, requiring optimized filtering strategies to retain such data while removing the most problematic pixels."

7. **p. 21, Fig. 6: 'The dotted lines denote the contour plots...' These contour plots are not mentioned in the text. If these are relevant, they should be discussed; if not, they should be removed.**

   Adjusted

   The contour lines represent the density distribution of data points in the (albedo, $\Delta A$) parameter space. We have now included a brief explanation and discussion of these contours in the text, highlighting that the largest persistence-induced biases occur in relatively sparsely populated regions.

We added on P8, L242 the line:
“The dotted contour lines indicate the density distribution of data points in the (*Albedo,* Δ*Albedo*) space, showing that the largest persistence-induced biases occur in relatively sparsely populated regions of the parameter space.”

**Technical Corrections:**

8. **p. 6, l. 165: What is meant with ‘numerical range’ - please explain or remove.**

   Adjusted

   This was a typographical issue arising from a LaTeX formatting error. The text has been corrected to explicitly state the NIR spectral range (745–773 nm).

   We changed the sentency to: “Additionally, the NIR band (745–773 nm) is used to constrain atmospheric scattering properties.”

9. **p. 7, l. 205: ‘nits%’ - should probably be ‘%’?**
   Adjusted

10. **p. 12, section B2: A reference to this section should be given in the main text.**
    Adjusted

    We have added a reference to Appendix B2 in the main text to guide the reader to the corresponding results for $CO_2$, CO, and the $CH_4/CO_2$ proxy ratio.

    We changed on P8, L224 the line:
    "Figure 5a present the relative persistence CH4 bias maps for each study region."
    to:
    "Figure 5a presents the relative persistence $CH_4$ bias maps for each study region; while the corresponding maps for $CO_2$, CO, and the $CH_4/ CO_2$ proxy ratio are shown in Appendix B2 (Fig. A2)."

    We added on P8, L245:
    "A similar relationship is observed for $CO_2$, CO, and the $CH_4/ CO_2$ proxy ratio (see Appendix B2, Fig. A4)."

    We added on P9, L260 (sentence introducing Fig. 5b):
    "The impact of this filtering is illustrated in Figure 5b and Table 1; the corresponding maps for $CO_2$, CO, and the $CH_4/ CO_2$ proxy ratio are shown in Appendix B2 (Fig. A3)."

11. **p. 21, Fig. 6: Caption: ‘panel (C)’ → ‘panel (B)’**

    Adjusted

12. **p. 23, Table 1: Please include also the number of data points before / after the filtering (or the percentage filtered out) for each scene.**

    Adjusted

    We have included the percentage of data points removed by the land–water filtering step for each scene in Table 1 (see last row). This allows a straightforward comparison across scenes while preserving the readability of the statistical results. The table caption has been updated accordingly to clarify this addition.

    Added the following sentence Caption in Table 1:
    “The last row reports the percentage of pixels removed by the land-water filter for each scene; values correspond to the full-physics retrievals, with differences for the proxy retrieval below 1 %.”

**References**:

European Space Agency (ESA), 2020a: Sentinel-5: ESA's Polar-orbiting Atmospheric Composition Mission in Support of Copernicus Services, Esa sp-1336, ESA Communications, Noordwijk, The Netherlands, https://www.esa.int/About_Us/ESA_Publications/SP-1336_Sentinel-5_ESA_s_Polar-orbiting_Atmospheric_Composition_Mission_in_Support_of_Copernicus_Services, 2020.

European Space Agency (ESA), 2020b. Copernicus $CO_2$ Monitoring Mission Requirements Document (CO2M MRD), Issue 3.0. ; Available at: https://esamultimedia.esa.int/docs/EarthObservation/CO2M_MRD_v3.0_20201001_Issued.pdf

European Space Agency (ESA), 2024. MicroCarb Mission Summary. Available at: https://database.eohandbook.com/database/missionsummary.aspx?missionID=858

Lorente, A., Borsdorff, T., Martinez-Velarte, M. C., Butz, A., Hasekamp, O. P., Wu, L., and Landgraf, J.: Evaluation of the methane full-physics retrieval applied to TROPOMI ocean sun glint measurements, Atmos. Meas. Tech., 15, 6585–6603, https://doi.org/10.5194/amt-15-6585-2022, 2022.