Reviewer 2

While satellite-based remote sensing provides good estimates of the aerosol optical depth (AOD), the same is not true of other aerosol parameters. The authors have developed an algorithm to use a combination of spaceborne measurements to improve aerosol (and surface) characterization.
The basic idea is that these measurements encompass some or all of the following: (1) a range of scattering angles (enabling observation of differences in angular dependence of aerosol and surface signals); (2) a wide spectral range (enabling observation of differences in spectral dependence of aerosol and surface signals); (3) polarimetry (enabling observation of differences in the polarization signatures of aerosol and surface signals, which relate to aerosol microphysical properties); and (4) high temporal resolution (enabling observation of the temporal variability of aerosol properties and differences in aerosol and surface signals over the relevant time period).
In particular, existing algorithms are unable to handle observations that are not collocated in time.
The authors take advantage of the fact that aerosol properties show temporal and spatial correlations. Their new algorithm (called SYREMIS) is generic and can be applied to a variety of satellite observations. They explore both LEO-LEO and LEO-GEO synergy. For the former, they test their algorithm on combined measurements from S5P/TROPOMI, S3A/OLCI and S3B/OLCI. For the latter, they apply their algorithm to S5P/TROPOMI, S3A/OLCI, S3B/OLCI and Himawari-8/AHI measurements.
The theoretical basis for this work is good, which is a strength of the study. However, there are missing aspects in the manuscript. In particular, the results do not adequately demonstrate the concept. There is not enough explanation of why the results are different between the existing methods and the proposed new approach, or why the authors believe the synergistic product is more accurate. Further, as written, the manuscript reads more like a news report than a research article. The results are described without any discussion of the broader scientific principles or implications. For a journal paper, it is crucial to go beyond descriptive reporting and provide insights that can be generalized or that significantly advance the understanding of the topic. Finally, there are several instances of poor grammar and typos. I recommend the paper to be carefully proofread. I recommend a major revision addressing all these issues before the paper is reconsidered for publication.

Response:
The authors thank the reviewer for his critical but very valuable comments. The missing aspects, pointed out by the reviewer, were carefully considered, and corresponding corrections were performed. Overall, this includes:

1. More detailed description of the physical basis of the synergetic approach, such as data preparation for synergy, forward modelling, GRASP algorithm inversion approach for SYREMIS synergy, and multi-pixel synergetic concept. We also emphasized the differences and advantages in comparison to the existing methods (Sections 1, 2).
2. The results are presented in more detail, showing advantages of the synergetic approach (Sections 2.4 and 3)
3. The scientific discussion is substantially extended throughout the manuscript.
4. The paper was carefully reviewed, and the English language was improved.

Specific Comments:
Line 174: 21 bands -> 24 bands
Response:
Corrected.

Table 2: What are the 19(24) spectral bands used in the LEO-LEO(LEO-GEO) synergy? The specific wavelengths need to be mentioned, especially because Lines 194-199 indicate that not all individual measurement bands were used.
Response:
In our study, we used specific spectral bands from OLCI, TROPOMI, and AHI sensors for the LEO–LEO and LEO–GEO synergy retrievals. We combined 9 bands from OLCI and 10 bands from TROPOMI, resulting in a total of 19 spectral bands: 340, 367, 380, 412.5, 416, 440, 442.5, 490, 494, 510, 560, 665, 670, 747, 753, 772, 865, 1020, and 2313 nm. For the LEO–GEO synergy, we combined 9 OLCI bands, 10 TROPOMI bands, and 6 AHI bands, accounting for the common 510 nm band shared between TROPOMI and AHI. This results in a total of 24 spectral bands: 340, 367, 380, 412.5, 416, 440, 442.5, 470, 490, 494, 510, 560, 639.1, 665, 670, 747, 753, 772, 856.7, 865, 1020, 1610.1, 2256.8, and 2313 nm. Table 2 is updated correspondingly.

Lines 198-199: “Accounting for the differences in the calibration and spectral bandwidth in GRASP algorithm is realized with application of the different requirements on the standard deviation of measurements fitting for the different spectral bands.” What does this mean?
Response:
Section 2 was substantially revised, and Appendix A was added to describe the relation between “the standard deviation of measurement fitting” and measurement “weighting”.

Section 2.2: The description of how the weighting of the different measurements is done is very unclear. Given that the weighting is one of the significant innovations in this work, this is a major drawback. It would help to have an equation outlining this process and some text explaining how the parameters are chosen, along with a clear description of the rationale. This would also help clarify what the parameters in Table 3 mean.
Response:
Updated Sections 2.2, 2.3, and added Appendix A describes the “weighting” due to measurements and a “weighting” due to a priori datasets (smoothness constraints) in GRASP algorithm and how they were used in SYREMIS synergy (section 2.2 - 2.4, Appendix A).

Lines 249-253: “In particular, in the SYREMIS/GRASP processing the surface properties are considered to be the constant within +/-6h over land and +/-0.5h over ocean (“Temporal threshold on surface variability” in Tables 3 and 4). For the vertical distribution of aerosol concentration, the temporal threshold +/- 3h over land +/-0.5h over ocean was applied (“Aerosol scale height variability” in Tables 3 and 4).” What is the rationale for selecting these values? As the authors correctly mention, correct selection of these constraints is crucial when the measurements are not coincident. However, there is no explanation of how they arrived at these values. There is some description of the constraints being relaxed compared to those for single instruments, but there needs to be a more detailed explanation of the rationale. Further, why are the constraints more relaxed for LEO-GEO than LEO-LEO?

Response:

BRDF parameters are defined by the intrinsic properties of the surface, like surface type, reflecting properties, topology etc, which are very stable in time. Therefore, land surface BRDF parameters do not change considerably during a day. The +/-6h threshold applied to BRDF parameters in the SYREMIS approach allows using almost the same BRDF parameters for all synergetic measurements during the day. This threshold can change depending on the pixel latitude due to different satellite overpass times at low and high latitudes. For the considered satellite synergetic constellation, +/-6h gives a 12h interval, which is sufficient to account for the stable surface within the day globally. The BRDF parameters' variability from day to day is controlled by surface temporal smoothness constraints. Both the temporal thresholds and smoothness constraints substantially increase the number of pseudo-multi-angular measurements in the synergy, which is crucial for BRDF parameters retrieval and discrimination of atmosphere and surface signals.

Overall, Section 2 was revised, providing the description of reasoning (Sections 2.1 - 2.3) and criteria to select the best retrieval setup (new Section 2.4). The Tables with parameters were modified to provide rather general information related to the synergetic measurements rather than providing specific information related to GRASP. The corresponding discussions are added in Section 2.

Figure 3: After harmonization, instrument weighting, and retrieval setup optimization, it seems that individual instruments perform as well as the combination. If this is true, then what is the point of using the combination? If not, the advantages should be clearly explained.

Response:

We demonstrate in this paper that the synergetic retrieval performs better than the retrieval from a single instrument. To better show that the validation figures were changed, the tables with statistical validation characteristics are added and the discussion of the synergetic results is extended. To avoid confusion, Section 3 was subdivided to the 4 subduction:

3.1 SYREMIS/GRASP LEO+LEO synergy performance versus AERONET

3.2 SYREMIS/GRASP LEO+LEO inter-comparison with GRASP single instrument retrieval over AERONET

3.3 SYREMIS/GRASP LEO+GEO synergetic performance versus AERONET

3.4 SYREMIS/GRASP aerosol and surface products global intercomparison

Lines 275-276: “The validation criteria are the same as was used for TROPOMI/GRASP retrieval evaluation (Litvinov et al., 2024; Chen et al., 2024a).” Even though the validation criteria have been discussed in detail in other papers, it would be useful to the readers to have a summary here.

Response:

The validation criteria are presented and discussed in the new Section 2.4 Remote sensing tests to optimize synergetic retrieval

Lines 280-281: The authors use the phrase “instrument extracted from the synergy”. How is this different from using the measurements from a single instrument? For example, how are SYREMIS/TROPOMI and SYREMIS/OLCI different from GRASP/TROPOMI and GRASP/OLCI?

Response:

The phrase “instrument extracted from the synergy” means we extract retrieved properties (aerosol or surface ones) from the synergetic product at the time step corresponding to a certain instrument. This is different from the properties derived from the independent single-instrument retrieval. The clarification and discussion have been added to the paper.

Figure 4 seems to suggest that TROPOMI alone performs better than using all instruments together. Why combine the instruments then? Also, OLCI results seem to be much worse than those from TROPOMI. What advantage does using OLCI measurements provide?

The same is true for the AE and SSA results (Figures 5 and 6). In fact, for the AE, the results are very different from AERONET results. I actually do not see much of a use for satellite-derived results, single or combined. Similar comments apply to Figures 9, 10 and 11. The LEO-GEO combination (Figures 12-14) seems to suffer from similar issues, with Himawari providing almost all the information in that case and the other instruments having negligible contributions. In Figure 15 (that is not referenced in the text), what do SYREMIS/TROPOMI LEO+GEO and SYREMIS TROPOMI LEO+LEO represent? What instruments are covered in these combinations?

Response:

We have revised Section 3 and the figures to better highlight the key points as suggested.

We used the following notation, explained in Section 3:

- SYREMIS LEO+LEO: TROPOMI denotes the TROPOMI retrieval results obtained from the SYREMIS LEO+LEO synergistic retrieval (combining TROPOMI and OLCI).
- GRASP/TROPOMI refers to the single instrument GRASP retrieval from TROPOMI-only measurements
- SYREMIS LEO+GEO: TROPOMI refers to the TROPOMI retrieval results extracted from the SYREMIS LEO+GEO synergistic retrieval (combining TROPOMI, OLCI, and AHI).

Similar notation was used for OLCI data extraction from the synergy and single-instrument retrieval.

The obtained results show improvements in AOD in comparison to the single-instrument retrievals (updated Section 3.2, Figs. 8, 11, Tables 8, 10). AE and SSA from the synergy are generally comparable with those from the TROPOMI/GRASP single-instrument retrievals, with slightly improved performance in certain statistical metrics, such as an increased number of matchups (Figs, 9,10, Table 9). At the same time, the results for the datasets associated with OLCI measurements are considerably improved for AOD, SSA in comparison to the single-instrument GRASP/OLCI retrieval (Figs. 11, 13, Table 11) and AE similar to the data extract for TROPOMI (SYREMIS LEO+LEO: TROPOMI, Figs, 9,12). Overall, the criteria to select the best approach is based on the following selections: 1. Performance in 1). AOD, 2) AE, 3)SSA 4) Number of pixels passed the high quality filtering. According to this, the synergetic approach clearly shows considerable improvements in comparison to the single instrument retrieval (Section 3.2). As summarized in our conclusions, TROPOMI (with the most information among other considered instruments) serves as the main driver in the synergistic retrieval.

Figure 8: What does QA>=2 mean? The meaning of that expression needs to be clarified. Also, it seems that the performance of SYREMIS, compared with GRASP, is better over land. That contradicts the authors' claim that the synergistic retrieval is better than the retrieval from individual instruments.

Response:

In TROPOMI/GRASP products, a quality flag (QA) is assigned to each pixel based on spectral fitting residuals and a moving window smoothness test, as described in Litvinov et al. (2024). Specifically, the QA flag has three categories: QA = 1: "marginal" retrieval quality; QA = 2: "good" retrieval quality; QA = 3: "very good" retrieval quality.

In the updated figures in Section 3 we applied the same data filtering approach. This does not change the main conclusion but helps to avoid confusion. The applied filter is described in Section 3. Results presented in Section 3.2 clearly show much better performance of the synergy in comparison to the single-instrument retrieval.

Lines 393-394: "One can see from Fig. 16 that, overall, SYREMIS/GRASP AOD retrieval corresponds well to VIIRS, MODIS, TROPOMI/GRASP and OLCI/GRASP products." I disagree. It seems to me that TROPOMI/GRASP results agree well with VIIRS results, but SYREMIS results differ considerably, especially over the Sahara and the Middle East (bright surfaces?).

Response:

Section 3.4 was revised. We emphasise that we provide only preliminary results here. More detailed analysis and inter-comparison will be the subject of the second paper on the synergy. We discuss that the inter-comparison shows qualitative agreement with the single instrument retrieval. At the same time, though the synergy performs better over AERONET stations (SYREMIS/TROPOMI vs GRASP/TROPOMI, Section 3.2), qualitative inter-comparison shows essential differences in AOD and BRDF properties between synergy and single instrument retrieval. In particular, in terms of AOD spatial distribution, TROPOMI/GRASP appears to agree better with SNPP VIIRS/DB than TROPOMI/SYREMIS, particularly over bright surfaces in regions such as the Sahara and the Middle East.

We are currently working on separate papers that will focus on a comprehensive evaluation, including quantitative validation with AERONET data and detailed intercomparisons with other satellite products. On the other hand, thanks to the synergistic use of multiple sensors, multiple daily observational angles, and cumulative multi-day observations, SYREMIS retrievals can better characterize surface BRDF. For example, the dynamics of the second and third BRDF scaling parameters illustrated in Figures 18 and 19 demonstrate this capability. Therefore, we have high confidence in the accuracy of TROPOMI/SYREMIS aerosol retrievals over bright surfaces. Overall, we plan to conduct a more comprehensive evaluation of SYREMIS retrievals compared to single-instrument retrievals in a separate dedicated study.

Note in the updated validation plot above, the number of datapoints N in each plot is different compared to the number of datapoints in the original Figs. 2 and 3 in the first submission of the manuscript; this is because the updated plots were created with updated AERONET Level 2 products. The latest access date to AERONET is 2025 July 18, which is about 2 years after the creation of the original plots in the first version of the manuscript. "