

Response to the report of reviewer #3:

We appreciate the detailed comments and suggestions from the reviewer, which are very helpful in improving the clarity of this work. Please find our responses with corresponding revisions below.

Interactive comment on “Inversion of multi-angular polarimetric measurements from the ACEPOL campaign: an application of improving aerosol property and hyperspectral ocean color retrievals” by Meng Gao et al.

Anonymous Referee #3 Received and published: 6 April 2020

The study aims at demonstrating the benefit of using synergistically hyperspectral and multi-angular polarimetric (MAP) observations to improve ocean color remote sensing, especially in the coastal zone, where aerosols are complex, relatively abundant, and highly variable. The approach is to use aerosol properties (size distribution parameters, index of refraction, optical thickness) retrieved from MAP data in a forward radiative transfer model to estimate the aerosol signal, therefore perform atmospheric correction of the hyperspectral measurements. To achieve this objective RSP and SPEX aircraft measurements acquired off the West Coast of California were used, and the retrievals of aerosol properties and, therefore, remote sensing reflectance were compared with AERONET-OC measurements. Uncertainties in aerosol retrievals are reduced substantially (factor of 2) when using polarization and reflectance instead of just reflectance data, and the retrieved quantities show some agreement with in-situ measurements. The authors conclude that the findings constitute a proof-of-concept for the PACE mission, i.e., MAP data would be used in a similar way to correct atmospheric influence on the OCI hyperspectral imagery.

The approach is technically sound, the inversion techniques appropriate and robust, and the data processing/analysis performed carefully, but several issues prevent publication of the manuscript. First, aerosol abundance during the flights analyzed is very small, i.e., about 0.02 at 865 nm. With such minimum loadings, the signal to correct is so small that even large errors in the aerosol model would still yield sufficient accuracy on the remote sensing reflectance. It is not surprising, therefore, that even though differences are relatively large between estimates of size distribution, real part of index of refraction, and single scattering albedo using 7rhos and 7rhos + 5Pols (e.g., Figure 5), the retrieved RSP remote sensing reflectance is similar. I suspect that simply using the aerosol information from the MERRA-2 data would have provided similar performance. In other words, the demonstration is not credible when using cases with almost no aerosols.

Thanks for the summary and the positive comments in our approach and analysis. Also thanks for the discussions on the small AOD in our study. Here we provide more clarifications here:

- 1) We agreed that the aerosol loadings in these two cases are small which is about 0.03-0.04 at 550nm, and 0.02-0.03 at 865 as the reviewer corrected pointed out. However, due to the small value of the remote sensing reflectance, accurate retrieval of the aerosol properties is still important to determine the remote sensing reflectance. As verified from radiative

transfer simulations with aerosols only, aerosol reflectance contributes to the same order of magnitude as the remote sensing reflectance at 400-550nm range. The following discussions are provided and revised in the Section 2 (second last paragraph):

“...Although the aerosol loading is small, its contribution is of the same order of magnitude as the water leaving signal between 400-550 nm range, and hence remains important for atmospheric correction. Therefore, both the retrieval of aerosol micro-physical properties and the water leaving signals require high accuracy of the measurements from RSP and SPEX Airborne.”

- 2) We agree that the similar remote sensing reflectance obtained using the aerosol properties obtained from the two different cost function may relate to the small optical depth, and several other factors. Please note that the available cases with co-located multi-angle polarimetric measurement and hyperspectral measurements are really rare. We revised our manuscript to state the importance for future studies and validation campaigns with various aerosol loading. Some discussions and revisions are provided in Section 5 (third paragraph):

“Meanwhile, we have shown polarization information can help to improve retrieval accuracy in the retrieval of aerosol optical depth, fine mode refractive index and SSA as shown in Fig. 5. Besides the theoretical retrieval accuracy analysis, validations with direct measurements are important to account for unknown uncertainties. The AOD results from polarimetric retrievals can be validated with ground-based measurement such as AERONET and lidar measurements such as HSRL, however, it is challenging to validate complex aerosol refractive index, SSA, and size distribution for the entire atmospheric column due to the lack of direct measurements. Such validation requires well-planned airborne field campaigns, concepts for which are under development (PACE validation plan 2020)”

- 3) Thank you for suggesting the use of MERRA2 aerosol model for atmospheric correction. We conducted the following evaluations:
 - a. We located the corresponding MERRA2 one hour aerosol product as archived in <https://oceandata.sci.gsfc.nasa.gov/> for the two cases in our study at 2017/10/23 21:33 and 2017/10/25 21:07 (file names are N201729621_AER_MERRA2_1h.nc and N201729821_AER_MERRA2_1h.nc).
 - b. We then located the MERRA2 pixels near the AERONET SeaPRISM site location and found that the corresponding MERRA2 AOD are 0.054, and 0.080 at 550nm for cases 10/23 and 10/25. Note that AERONET AOD at 550nm are 0.034, while HSRL AOD at 532nm are 0.036 similar to both days. Our retrieved AODs at 550nm are 0.033 for Case 10/23 and 0.031 for Case 10/25. The MERRA2 AOD overestimate AERONET AOD by 0.02 and 0.046 respectively.
 - c. We estimated the amount of aerosol contribution to the remote sensing reflectance (ΔRrs) by using the single scattering approximation, namely, $\Delta Rrs \sim AOD \times B/\pi$, where B is the aerosol backscattering fraction at 550nm (around 0.2 for our cases). We have $\Delta Rrs \sim 0.001$ and 0.003 for Case 10/23 and 10/25 respectively, larger than the difference (<0.0005) between our retrievals and the AERONET Rrs at 550nm, especially for case 10/25.

- d. Therefore, we concluded that MERRA2 aerosol model is not ideal for the atmospheric correction in our studied cases. However, the suggestion to investigate MERRA2 aerosol model is interesting. We can study whether MERRA2 aerosol model can be used as a way to better select initial values in the retrieval algorithm in our future study.

Second, HARP2 on the PACE mission will not measure in the shortwave infrared, so the demonstration should have been made using 5rhos and 5rhos + 5Ps to better mimic/represent the PACE capabilities.

Thank you for the suggestion on removing SWIR bands in aerosol retrievals. In this study we aim to provide best retrievals using the full capability of the RSP sensors, although DoLP measurements in SWIR bands are not used due to issues discussed in the manuscript. We did not intend to make RSP measurements to look the same as HARP or SPEX. Even after we removed the RSP SWIR bands, RSP are still different than HARP and SPEX with many more viewing angles and different measurement uncertainties. However, the algorithm and procedures using the current RSP measurements can be applied to other polarimetric measurements as a proof of concept demonstration to assist hyperspectral atmospheric correction. Furthermore, there are SWIR measurements in PACE OCI, which may have higher SNR, and it is potentially can be used to assist the MAP retrievals. We revised our manuscript as follows:

“The percentage uncertainties of the polarizations in the two SWIR bands further increases when the DoLP value decreases. We have tested the effects of the DoLP at the two SWIR bands on the aerosol retrieval and found that including them does not improve the retrieval accuracies, so the SWIR DoLPs are not used in our retrievals. Moreover, the PACE MAPs do not include polarimetric SWIR measurements but PACE OCI includes several SWIR bands measured at a single viewing angle and may have higher accuracy, a synergy of PACE OCI SWIR with MAP measurements may further improve aerosol retrievals.”

Furthermore, no comparison was made with remote sensing reflectance retrievals performed by the standard algorithm applied to aircraft RSP and SPEX data (possible even though for SPEX the spectral range is limited in the near infrared), in order to evaluate potential improvements by the proposed method.

This is another good suggestion to apply standard atmospheric correction algorithm on RSP and SPEX data. However, this requires generating appropriate aerosol lookup table for the exact RSP and SPEX bands which are not currently available in the processing software. This suggestion deserves a separate study which is out of scope of this work.

Finally, examining Figure 6, one cannot convincingly conclude that SPEX-derived hyperspectral reflectance in the blue agree with the in-situ measurements, i.e., in Section 4 the statement “The resulting hyperspectral water leaving reflectances agree well with the ARONET OC and MODIS OC products” is incorrect.

Thank you for the comments. We made the following revisions to provide more details:

“... ”

The retrieval uncertainties on RSP Rrs is within 0.0004 sr^{-1} (same to SPEX Rrs), while the comparison of the two cases with the AERONET Rrs shows a difference less than 0.0003 sr^{-1} for RSP Rrs, and a maximum difference of 0.0004 sr^{-1} (Case 10/25) and 0.001 sr^{-1} (Case 10/23) for SPEX Rrs. The difference of SPEX Rrs for Case 10/23 is larger than the retrieval uncertainties which is likely due to the radiometric uncertainties from the sensors.

“

We have also added more discussions on the difference between RSP Rrs, SPEX Rrs and AERONET. On the comparison between RSP and AERONET Rrs:

“... The RSP Rrs at 470 and 550nm are 0.0026 and 0.0020 respectively for Case 10/23, and 0.0025 and 0.0021 respectively for Case 10/25 as shown in Table 3. For AERONET Rrs, the values at 442, 490 and 550nm are 0.0027, 0.0028, 0.0017 sr^{-1} for Case 10/23, and 0.0028, 0.0029, 0.0017 sr^{-1} for Case 10/25. Using the interpolated value of AERONET Rrs at RSP bands, the difference between RSP and AERONET Rrs are within 0.0003 sr^{-1} .

...”

More discussion on comparison of SPEX Rrs and AERONET Rrs can be found in the revised file and the diff file.

The above criticisms notwithstanding, the study is interesting. The procedures for estimating the atmospheric interference are well defined. I would recommend showing retrievals over the entire 2 flights (along and perpendicular to the coast) to capture varied aerosol and water reflectance situations, even though in situ measurements may not be available, compare the remote sensing reflectance retrievals with those of the standard algorithm, and evaluate against the aircraft lidar measurements and satellite products, but this would require a new submission.

Thank you for the interest in the study and the suggestions to include the whole flight retrieval.

We have conducted studies on a flight track over water of day 10/23, and compared the retrieved RSP AOD (with polarization measurement) with the HSRL AOD as shown in the Figure 1 below. Over the flight track, the AOD variations are very small mostly around 0.02-0.04 (HSRL 532nm). For the day of 10/25, there are a limited number of pixels over water for analysis (plot not shown), and the AOD are around 0.03~0.05(HSRL 532nm). Therefore we are not discussing these results in the manuscript to capture aerosol variations, instead we only focus on the representative cases. For the study using standard atmospheric correction algorithm, as we have discussed previously, it requires new development of lookup table which is outside current study scope.

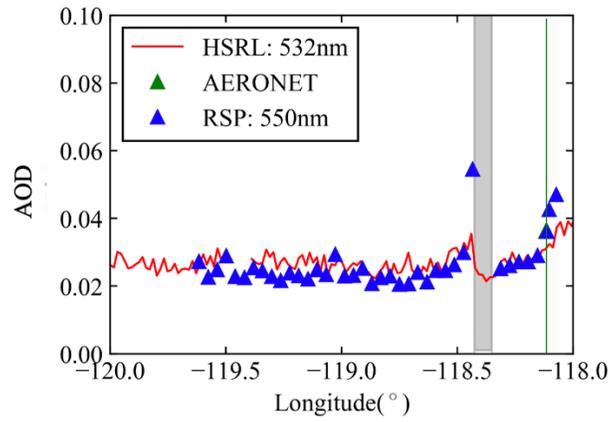


Figure 1. Retrieved RSP AOD and the HSRL AOD for Day 10/23. The green line indicates the location of the AERONET site where AERONET AOD coincides with the retrieved RSP AOD; grey area indicates the location of the island with data screened.