Author response to reviews of "Analysis of simultaneous aerosol and ocean glint retrieval using multi-angle observations" by Kirk Knobelspiesse et al.

Feb 8, 2020

We would like to express our gratitude to the reviewers for their thorough and positive assessment. Below are our individual responses to each reviewer, reviewer's text in italics.

We would also like to note that we have added supplementary material at data.nasa.gov at the following location:
https://data.nasa.gov/Earth-Science/MISR_MODIS_AtmCorrection/sg4r-ftwb
This contains figures similar to 3, 4, 5 and 7, but for each of the 7,000+ simulations at various geometries and parameter states. We have added a note regarding this in the 'code and data availability section.

Anonymous Referee #2

The manuscript describes in great details a theoretical analysis of the information content attached to the MISR satellite instrument in one given spectral band (i.e., centered on 865 nm) but performing acquisitions for nine distinct viewing directions. In this part of the spectrum, most of the ocean might be considered as virtually totally absorbing that is to say that the water leaving radiance is nil. Even if the assumption is a little restrictive (e.g., intense bloom), it can be advantageously used to get purely atmosphere and water surface information. Here, the authors discussed how accurate could be achieved retrieval of some key parameters concerning aerosols and air-water interface roughness given the nine pieces of information provided by the MISR directional measurements. This information content assessment is performed upon a sophisticated Bayesian approach and outcomes of a well-established radiative transfer code. The results obtained for a limited set of "test cases" show not very surprising results: for low aerosol optical thickness (AOT), surface parameters are better retrieved and when AOT increases the aerosol model is better retrieved.

The manuscript is well-written with a sound mathematical background for such analysis. However, the parameters used in the analysis could be expanded to better delineate the optimal number of parameters to be estimated. More importantly, the primary goal of the analysis is not very clear and should be specified; is the study dedicated to: (i) estimation of aerosol microphysical parameters, (ii) atmospheric correction for ocean color purposes, (iii) sea surface roughness characterization (or (iv) all on the same time). For the first case, the study should include more aerosol parameters to be tested (single scattering albedo, mean radius and variance of the modal size distribution...). For (ii), the most important parameter is the spectral variation of the atmospheric radiance. As to (iii), the surface model should be furthered with inclusion of foam formation, for instance, and discussed in light of the uncertainties attached to wind-sea-roughness model with the isotropic and directional implementation (see (Breon Henriot, 2006; Munk, 2009)) and compare with other technical approaches (see (Harmel Chami, 2013)). In any case, the representativeness of the parameters retrieved from the near-infrared band should be analyzed over the visible-NIR spectral range. The study could conclude on the benefits of using the methods developed for the "aerosol" algorithms to the "atmospheric correction" ones, and respectively.

Our goal is item (ii). The final paragraph of the abstract starts with: "An algorithm designed upon these principles is in development. It will be used to perform an atmospheric correction with MISR for coincident ocean color (OC) observations by the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument, also on the NASA Terra spacecraft."
To further clarify we added the following language to the conclusion (new language in italics)

The primary purpose of this research is to establish that multi-angle measurements from the MISR 865nm channel are sufficient to determine the combined aerosol and sun glint state *for the purposes of AC.*

We also added the following paragraph to the conclusion:
The intent of this algorithm is to provide for an AC that can be applied to observations at VIS wavelengths. We build upon an approach (Mobley et al., 2016) that has been used for OC remote sensing for decades. This rests on two assumptions. First, as is described above, premise that the ocean body does not contribute in the NIR, and that the aerosols can be treated as spherical. Second, the approach hypothesizes that aerosol refractive index is spectrally invariant within VIS-NIR wavelengths. Of course, this is not always the case, as is reviewed by Frouin et al., 2019. However, with this algorithm, we show improvement over single view angle techniques, including glint/wind speed sensitivity and a better ability to identify aerosol microphysical properties. What this provides for is the means to atmospherically correct MODIS observations, and use that instrument's higher SNR and more spectral channels to determine the ocean state. A complete algorithm would probably utilize the VIS MISR channels as a verification that the retrieved ocean and atmosphere state is correct, and if not, be utilized in an iterative correction approach (Wang and Gordon, 1994, studied this prior to the launch of MISR). The scope of this paper is to verify that a single MISR NIR channel is sufficient to resolve the parameters traditionally used for AC. We find that it is, and then some.

Regarding point (i), the aerosol microphysical properties are varied as described in table 1. Note that these aerosol models are used as such for typical AC retrievals, but in our case are free parameters related to aerosol 'relative humidity' (which modifies the refractive index and size of a given mode) and fine mode fraction (which governs the ratio of fine to coarse mode). This somewhat constrained parameterization is a requirement of the available information content, although it is less constrained than standard AC.

For point (iii) we found that the inclusion of sea foam in our simulations had negligible influence on information content, although proper handling would be required for AC. The Breon and Henriot reference regards the somewhat separate case of POLDER, which has access to the polarization state, more viewing angles, and different solar/view geometry, but we added that to the reference to Harmel and Chami in the introduction.

Minor comments:
The study is presented based on a few “test cases” corresponding to some AERONET- OC cases. First, those sites are mostly coastal with non-null NIR water-leaving radiance. Second, for such a theoretical study there is no need to restrict the analysis to very few and too specific conditions. For the sake of completeness, this test cases should be removed and replaced with a complete set of configurations, for instance sun angle from 0◦ to 90◦, aerosol optical thickness from 0 to 1, wind speed from 0 to 12 m/s (of course, actual values are at the discretion of the authors).
The reviewer has misunderstood our study, which we will attempt to resolve in the text. Our ‘test cases’ were chosen to simply identify specific geometries for which we know we already have a satellite – ground matchup. Beyond identifying real observed geometries (which span a range from high to low solar zenith angles) this offers the advantage that subsequent analysis with retrievals can be compared to this work. This study assessed retrieval capability for 1008 parameter combinations described in Table 2 for each of the seven geometries. Thus, Figures 3, 4, 5 and 7 represent specific geometry/parameter results, while figures 6, 8, 9 and 10 are represented as assessments in aggregate for many results.

Additionally, Figure 1 shows the relationship between observed solar zenith angle and relative azimuth angle. Both of these things strongly control the presence and location of the observed glint. We initially performed this study by stepping over a range of solar zenith and relative azimuth values but realized that it would be inclusive of geometries that are not, in fact, observed by MISR. We thus shifted gears and used real observation geometries instead.

While our approach was described in several points in the paper (such as section 2.6, implementation), we realize that reading section 2.3 could lead to misconceptions. So, we added a sentence to the end of that section to clarify.

Additionally, we have placed supplementary material with the results of each of these simulations as noted above.

Technical comments:
Through the manuscript: remove statement on future works, this gives the impression that everything is still to be done.

We removed these statements where it made sense to do so.

Title: specify the main purpose: atmospheric correction, aerosol retrieval. . . (see major comments)

We hope to have sufficiently address this as described above.

L.16: “virtually black”

We modified ‘black’ to ‘strongly absorbing’

L.125: it would be very interesting to include more complex aerosol models than those obtained based on Mie assumptions (non-spherical, heterogeneous. . .)
Yes. But given our expectations based on previous information content assessments (ie Knobelspiesse, K., et al. Analysis of fine-mode aerosol retrieval capabilities by different passive remote sensing instrument designs, Opt. Express, 20(19), 21457-21484 , 2012.) we are unlikely to have the information content necessary to distinguish heterogeneous aerosols. Non spherical aerosols, on the other hand, are something we would like to address in an upcoming paper once we have incorporated that type of scattering into our radiative transfer model.

Table 1: specify the distribution type (in number, surface or volume) for the modal Parameters
We added a sentence in the Table 1 caption to note that the size distributions are log-normal, and referenced Ahmad et al 2010 from which the models are taken. It existed previously in section 2.1.

L.138. Provide the values of the increments used

We had this in the original manuscript but were unsure if it should be included. Now it is.

L.156: foam should be considered but if not you have to remove wind speed greater than a certain threshold (8, 10 or 12 m/s)

The largest assessed wind speed value was 7.49m/s, and as noted above inclusion of foam had no impact on our results. Foam would be considered in an actual retrieval.

Section 2.3: to be removed

We don't follow why this should be the case, unless it is referring to previous misunderstanding about the range of simulated values. We updated this section to hopefully clarify that issue.

L.199: "a less common extremely low θ_s(20◦)", why is it less common, actually we can have sun zenith angle = 0◦ for subtropical acquisitions.

Not with MISR, because it is on the Terra spacecraft in an inclined orbit with a 10:30am local equator crossing time. For example, in the 2020 summer solstice orbit, the minimum solar zenith angle was 14.71 degrees, maximum 80.91 degrees. The minimum values are larger at other times of the year, such that for the 2019 winter solstice the minimum value was 20.86 degrees, and 21.5 degrees at the 2020 spring equinox.

L.209: I would say: "the partial derivatives of the simulated signal in the vicinity of the retrieved parameters"

updated, thanks

L.211: in equation with δmj , mj shouldn't be bold.

Corrected, thanks

L.220: PDF not defined

This is, actually, defined in the introduction

L. 221: "measurement space is locally linear"? "locally continuous", instead?
Ok, that's better. Technically, we usually approximate the Jacobian with a forward difference calculation, which does mean locally linear, but we haven't gone into that detail in this manuscript.

L.253: it is not very clear to me, why eight dimensions?

The number of dimensions is n + n, where n is the number of parameters. We have a result for each 'node' in our lookup table (which has n dimensions), and each result is an n dimensional volume.

Table 4: σppis also a function of sun zenith angle

True, however, solar zenith angles where uncertainty has a meaningful contribution to total uncertainty are > 70.

References

Breon, F. M., Henriot, N. (2006). Spaceborne observations of ocean glint reflectance and modeling of wave slope distributions. Journal Of Geophysical Research-Oceans, 111, C06005.

Harmel, T., Chami, M. (2013). Estimation of the sun glint radiance field from optical satellite imagery over open ocean: multidirectional approach and polarization aspects. Journal of Geophysical Research, 118(1), 1–15. https://doi.org/10.1029/2012JC008221

Munk, W. (2009). An Inconvenient Sea Truth: Spread, Steepness, and Skew- ness of Surface Slopes. Annual Review of Marine Science, 1(1), 377–415. https://doi.org/10.1146/annurev.marine.010908.163940

Thank you for these. We added Munk and Breon & Henriot, Harmel and Chami was already listed.