Review of manuscript submitted to AMT:

Title: Effective uncertainty quantification for multi-angle polarimetric aerosol remote sensing over ocean, Part 1: performance evaluation and speed improvement

Authors: Meng Gao et al.

General Comments

In this paper, the authors analyze theoretical uncertainty estimates and validate them using a Monte Carlo approach to generate error statistics. A previously developed Fast Multi-Angle Polarimetric (MAP) Ocean coLor (FastMAPOL) retrieval algorithm is used to carry out the retrievals and quantify uncertainties for both synthetic HARP2 (Hyper-Angular Rainbow Polarimeter 2) and AirHARP (airborne version of HARP2) datasets. The FastMAPOL retrieval algorithm is based on neural network (NN) forward vector radiative transfer model (VRTM) simulations pertinent for a coupled atmosphere-ocean system. The NN forward radiative transfer models are trained using synthetic data generated by the VRTM. For practical application of the appraoch to uncertainty evaluation in operational data processing, the authors apply a previously developed automatic differentiation method to calculate derivatives (Jacobians) analytically based on the neural network models.

Both the speed and accuracy associated with the quantification of uncertainties for retrievals based on MAP data are presented and discussed. Pixel-by-pixel retrieval uncertainties are evaluated for synthetic data as well as data obtained in AirHARP field campaigns.

The authors argue that the methods and results presented in this paper can be used to evaluate the quality of data products, and guide algorithm development based on MAP measurements for current and future satellite systems.

The paper is generally well written and the results appear to be robust and valuable. Therefore, I recommend that the paper be published after minor revisions outlined below.

Specific Comments

- On line 6, the authors mention "nonlinearity of radiative transfer near the solution". Since the VRTE is a linear equation, the authors should clarify what they mean here and use proper wording.
- line 53: the statement "the forward model is linear near the solution" also needs rewording, because the RTE is a linear equation.
- line 54: change "With MAPs, theoretical uncertainties...." to something like "For MAP measurements, theoretical uncertainties...."

- Line 62: change "error propagation does but require" to error propagation but requires"
- line 64: change "With MAPs, theoretical uncertainties...." to something like "For MAP measurements, theoretical uncertainties...."
- Line 74: change "Several approaches has been proposed" to "Several approaches have been proposed"
- Line 78: explain what "non-linearity around the truth" is supposed to mean
- change "properties retrieved directly by the MAP" to "properties retrieved directly from the MAP data"
- "more advanced instruments" please be more specific
- Line 114 "Section 4. quantified" → 'Section 4 quantifies"
- Line 115 "Section 5. quantified" → 'Section 5 quantifies"
- Line 125: "There are two MAPs on PACE" → "There are two MAP instruments on PACE"
- Line 147: "lower-dimensionality retrievals" – please explain.
- Line 158: "assumed as a combination of five lognormally-distributed aerosol sub-modes" – please justify this choice
- Line 175: "the spectral ocean color remote sensing reflectance ($R_{rs}(\lambda)$) is derived based on the retrieved aerosol properties through atmospheric correction" – a physically more satisfactory and accurate approach is presented by Fan et al. (2021).
- Line 192: "STIR is based on the Levenberg-Marquardt algorithm combined with ..... " – Please summarize the advantage of the STIR method compared to a "standard" Levenberg-Marquardt algorithm.
- Equation (14) – a physically more satisfactory and accurate approach consistent with the coupled atmosphere-ocean system is provided by Fan et al. (2021).
- Line 354: "Note that the synthetic data is computed directly using the vector radiative transfer model, but the NN forward model is used in the retrieval algorithm." – Please explain the significance/advantage of this approach.
- Line 415: "retrieval algorithms can be further improved, for instance, by including additional a priori constraints" – what kind of constraints? – please be more specific.
- "Less number of measurements are" → "A smaller number of measurements is"
- Line 440: "Higher measurements are generally" → '' A larger number of measurements is generally"

- Line 450: "makes retrieval cost more uniform" – not clear, please rewrite.
- 495: "a more complicated ocean bio-optical model" → "a more complete and realistic ocean bio-optical model"

Technical Corrections

In general this paper is well written, and I did not spot any typographical or grammar mistakes, except for the following:

- Line 204: "explicit a prior information" → "explicit *a priori* information"
- Line 206: "we assume Sa" → "we assume $\mathbf{S}_a$"
- Line 207: "assumed a prior " → "assumed *a priori*"
- Line 329: "Rrs" → "R_{rs}"
- Line 337: "their difference are quantified" → "their difference is quantified"
- Line 405: "errors are found sufficiently to evaluate" → 'errors are found sufficient to evaluate"
- Line 518: "based on a high-cost function" → "based on a failure to properly minimize the cost function"

Reference

Fan, Y., W. Li, N. Chen, J.-H. Ahn, Y.-J. Park, S. Kratzer, T. Schroeder, J. Ishizaka, R. Chang, and K. Stamnes, OC-SMART: A machine learning based data analysis platform for satellite ocean color sensors, Remote Sensing of the Environment, 253, 112236, 2021.