Comment on amt-2022-112
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The paper by Gao et al. validates a Bayesian uncertainty propagation model against the *real* uncertainty estimate from analyzing synthetic retrievals. The simulation study indicates that the theoretical uncertainties of the retrieved pixel aerosol quantities basically reproduce the real retrieval uncertainties in most cases, though with certain degree of underestimates. This is a major finding and should be useful for aerosol and ocean color remote sensing using PACE polarimeters. Another valuable observation is about the importance of sample size for uncertainty estimate. The authors shows the increased robustness of their uncertainty analysis when the sample size increase from 50 to 1000. Following the validation, retrievals were performed using the real observations from AirHARP field measurements and the Bayesian uncertainty estimate model. In algorithm development, the authors deployed the FastMAPOL approach, which couples NN based RT calculation and the automatic difference method for Jacobian evaluation. These two elements ensure the efficiency of the uncertainty model assessment in the present work.

Overall, the paper was well-written. I have the following four comments for the authors to consider to clarify their approach:

1. Do I understand correctly that the retrieval results for statistical analysis (e.g. those in Figs. 5-6) subjected to certain the convergence criterion? For example, the cost function needs to be less than or equal to the metric unit when the retrieval is flagged to be successful so that the results are further used in the uncertainty analysis. Associated with this question, what is the success rate of the retrieval?

2. Table 1 is commendable as it lists the range of 11 retrieval parameters which further decides the a priori matrix used in retrieval. Could the authors comment on whether there is potential impact of the a priori on the conclusion? For example, if we relax the upper
bound of the imaginary part of refractive index to be larger (e.g. 0.1 or larger for some strongly absorbing aerosols), will the Bayesian model based uncertainty still mimic the real uncertainties, or there might be additional underestimates of uncertainty?

3. Eq.(5): Is the modeling error (e.g. five size components of aerosols, Cox-Munk ocean surface, etc) excluded or included in the piece of VRTM model uncertainty "sigma_{VRTM}"? I'm curious in this aspect since in real data retrieval (e.g. the demonstrated AirHARP retrieval), one of the major error sources is the modeling errors. To enhance the connection of synthetic retrieval and AirHARP retrievals, it would be great if modeling error is included in the Bayesian model via RT simulation uncertainty "sigma_{VRTM}" and then via Eqs. (5)-(6).

4. What is convergence metric for AirHARP's real data retrieval? Is it consistent with the those used in the synthetic retrievals?