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Comment on amt-2021-274

Anonymous Referee #1

Referee comment on "Enhancing MAX-DOAS atmospheric state retrievals by multispectral polarimetry – studies using synthetic data" by Jan-Lukas Tirpitz et al., Atmos. Meas. Tech. Discuss., <https://doi.org/10.5194/amt-2021-274-RC2>, 2021

The article "Enhancing MAX-DOAS atmospheric state retrievals by multispectral polarimetry - studies using synthetic data" by Tirpitz et al. explores the potential benefit of including information about the polarisation state of scattered sunlight in the retrieval of vertical profiles of trace gas concentrations and of aerosol properties and abundances. This topic has until now been largely overlooked in the MAX-DOAS literature, partly because of the challenges it poses on the forward model, on the inverse modelling and perhaps also because of technical challenges in the development of a multispectral sensor capable of taking such measurements. It is however highly relevant to make such an assessment for the MAX-DOAS technique because from other applications in atmospheric composition research (e.g. with ground-based or satellite radiometers) it is well-known that making use of polarization enhances the information content and accuracy of aerosol retrievals.

Other noteworthy aspects of this study are (1) the implementation of a combined aerosol and trace gas retrieval in a single optimisation step, allowing for optimal propagation of errors in the measurements and in the a-priori assumptions into the uncertainty estimates of the many parameters that are retrieved and (2) the retrieval of micro-physical properties as described by the Mie model, which is more sophisticated in its description of aerosol properties compared to the more simple aerosol models used in MAX-DOAS studies until now.

I find the manuscript very well written, thorough and despite the high level of complexity of this subject certainly understandable for the target audience. The impact of different measurement modes (S,P,I,A) on the retrieval accuracy is quantified and interpreted in great detail. Questions such as on the impact of high aerosol abundances and the impact of spatio-temporal variability are addressed and provide relevant insights, for instance to those who will use MAX-DOAS data for comparison studies.

Some important conclusions are: (1) including polarisation affects mostly the accuracy of the aerosol-related quantities, (2) the impact on trace gas VCDs is limited (almost negligible) and (3) the impact is highest for the surface layer (both aerosols and trace gases).

It could be considered a limitation of this study (by itself) that it is based solely on simulations, making it difficult to judge the real impact of these algorithmic developments in practice. From this perspective, the summary of the main findings of a complementary study on field data (Tirpitz 2021) in the Outlook section adds a realistic perspective to the challenges met when implementing (and validating) these methods in practice. This is a valuable addition to the present study.

I recommend the manuscript to be published as is, after the following minor issues have been addressed:

- p. 11, l.309 The approach to model the aerosol bulk extinction efficiency to be constant with altitude limits the possibility to retrieve vertical aerosol profiles with different aerosol types at different altitudes (e.g. a mixture of soot, nitrate aerosols and sea salt in the lower part of the atmosphere and desert dust at higher altitudes). This is a limitation that could be mentioned in the manuscript.
- Fig. 3. Please add to the legend the meaning of the horizontal lines corresponding to each histogram (e.g. median)
- p. 23, l.485 "... if measurements are performed a only two ... " please rewrite "a", e.g. "at" / "for".
- p. 27, l.546-547 It could be considered to leave out the last part of this sentence because of redundancy: "(the effective ... polarimetric measurements)"