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Atmospheric Measurement Techniques Discussions

Interactive comment on "Cloud heterogeneity effects on cloud and aerosol above cloud properties retrieved from simulated total and polarized reflectances" *by* Céline Cornet et al.

Anonymous Referee #2

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The paper investigates errors due to cloud heterogeneity on operational retrieval algorithms developed for the POLDER radiometer. The methodology is appropriate: In a first step, realistic artificial cloud fields are generated using the model 3DCLOUD. Three cloud types with the same mean optical thickness are generated: a flat cloud, a bumpy cloud and one with fractional cloud cover. In a second step a 3D Monte Carlo radiative transfer model is applied to generate synthetic POLDER observations (simulations on fine spatial resolution are averaged over 7km x 7km to mimic POLDER pixels). The third step is to apply the operational POLDER algorithms on the synthetic data and compare the results with the known truth (artificial cloud fields). The following parameters are investigated: cloud optical thickness, cloud albedo, cloud top pressure,

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aerosol optical thickness above cloud, and cloud size distribution parameters (effective radius and effective variance). The results show that all parameters except the size distribution parameters are highly biased compared to the truth.

The study is a very important validation of the POLDER algorithms, since it provides error estimates of the retrieved parameters due to cloud heterogeneity. The results show, that cloud heterogeneity can not be neglected and it should be taken into account in future retrieval algorithms.

The paper is well structured and quite well written. I recommend to publish the paper after revision (see comments and technical corrections).

Comments:

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- There are other studies related to this one by A. Stap et al. They have investigated the errors due to cloud heterogeneity on aerosol retrieval algorithms for partially cloudy scenes, also developed for the POLDER radiometer. These could be mentioned in the introduction.

F. A. Stap, O. P. Hasekamp, C. Emde, and T. Röckmann. Multiangle photopolarimetric aerosol retrievals in the vicinity of clouds: Synthetic study based on a large eddy simulation. Journal of Geophysical Research: Atmospheres, 121(21):12914-12935, 2016. 2016JD024787.

F.A. Stap, O.P. Hasekamp, C. Emde, and T. Röckmann. Influence of 3D effects on 1D aerosol retrievals in synthetic, partially clouded scenes. J. Quant. Spectrosc. Radiat. Transfer, 170:54 - 68, 2016.

- Since the retrieval errors due to cloud heterogeneity are large, the conclusion of the study should be that one should develop new retrieval algorithms, which somehow consider cloud heterogeneity. I miss this conclusion in the introduction and/or conclusions section.

Steps in this directions are presented in the following papers:

W. Martin, B. Cairns, G. Bal, Adjoint methods for adjust- ing three-dimensional atmosphere and surface properties to fit multi-angle/multi-pixel polarimetric measurements, J. Quant. Spectrosc. Radiat. Transfer 144 (2014) 68–85 doi:10.1016/j.jqsrt.2014.03.030

W. G. Martin, O. P. Hasekamp, A demonstration of ad- joint methods for multi-dimensional remote sensing of the atmosphere and surface, J. Quant. Spectrosc. Radiat. Trans- fer 204 (Supplement C) (2018) 215 – 231 doi:10.1016/j.jqsrt.2017.09.031

A. Levis, A. Aides, Y. Y. Schechner, and A. B. Davis, Airborne Three-Dimensional Cloud Tomography. In Proceedings of the IEEE International Conference on Computer Vision 2015 (ICCV15), pp. 3379-3387 (201 5). Available online at: http://www.cv-foundation.org/openaccess/content_iccv_2015/html/Levis_Airborne_Three-Dimensional_Cloud_ICCV_2015_paper.html

A. Levis, Y. Y. Schechner, and A. B. Davis, Multiple-Scattering Microphysics Tomography. In Proceedings of the 30th IEEE/CVF Conference on Computer Vision and Pattern Recognition (CVPR17). Available onli ne at: http://openaccess.thecvf.com/content_cvpr_2017/papers/Levis_Multiple-Scattering_Microphysics_Tomography_CVPR_2017_paper.pdf

- The core of the study, the 3D radiative transfer (RT) model 3DMCPOL, is not described (only reference Cornel et al. 2010 is given). There should be a brief description on which methodology is used to solve the vector radiative transfer equation and also on the accuracy. Also later, in the results section, it is not mentioned, how accurate the radiative transfer simulations are. Can we trust the RT results, has the model been validated? The first paragraph in section 2 provides a short description of the cloud model 3DCLOUD; I would expect a similar description for 3DMCPOL.

- p5, l4: "To remain consistent with assumptions made within POLDER operational

algorithm, an oceanic surface with a wind speed of 7 m.s-1 is included for total reflectances while a black surface is included for polarized reflectances." -> This is an odd assumption. I think that this could introduce large errors, because the sun-glint is highly polarized. Why is the surface inconsistently included in the POLDER operational algorithm? Is there any document where this assumption is justified. Please explain/discuss this issue.

- p5, l17: "Note that in the three cases, the operational algorithm retrieves a cloud cover equal to one." -> can the operational algorithm retrieve cloud cover different from one? If yes, why does it not work for the fractional cloud?

- p.6, l1: "That confirms that heterogeneity parameters can be at first order used to characterize plan-parallel bias" -> could the heterogeneity parameter be derived from observations?

- p.6, l31: "Contrarily, using 1D cloud radiative model in the inversion and in the direct computation as it is done in the operational algorithm, is coherent and leads to a sound cloud albedo. The plane-parallel bias is indeed almost canceled."

This sounds as if the operational algorithm would retrieve a good cloud albedo, but it does of course not. The reality always "uses" a 3D radiative transfer model, so retrieval algorithms based on 1D RT models are always inconsistent and yield wrong results.

- p7, l1: "Albedos are simulated simply by summing the proportion of the Monte-Carlo photons going up at the top of atmosphere." -> This is then not the cloud albedo but the total albedo, since it includes also contributions from molecular scattering and surface reflection, right?

- p8, Sec4.2: The effective variance retrieval uses the amplitude of the surnumerary bows. The aerosol above cloud retrieval (Sec 4.3) obtains information about AOT from the attenuation of the cloud bow. If effective variance and AOT above cloud both influence the amplitude of the cloudbow region, how does the retrieval distinguish between

higher AOT and narrower size distribution? Does the amplitude also depend on cloud optical thickness?

- Sec. 4.2: Is the optimal estimation method a good approach for Reff/Veff retrieval based on the polarization of the cloudbow region? You write that the radiance does not fit very well, so that the retrieval does not converge, although the retrieval of the size distribution parameters is very accurate. I would think that the retrieval should not minimize the fit to radiances but it should only fit the position of the cloudbow and its amplitude. This could be realized using an optimal estimation approach but may be a simple lookup-table method would also work well. Somehow the retrieval should provide a criterion, whether it provides good results or not, here the cost function is not a good number for the quality of the retrieval.

- Sec. 4.2: "For the misrepresentation of 3D effects, we add 7.5% error in the cloudbow direction and 5% elsewhere." -> how are these errors estimated? Please justify.

- Table 3: I can not believe that for SZA=40° the difference between true and retrieved AOT and Angstroem coefficient (here also SZA=20°) is exactly 0.0 (with 3 digits accuracy). Please explain why it is exactly the same.

Technical corrections:

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p2, l27 ff.: "Indeed, for oblique ..." -> the sentence is too long and confusing. It is not clear whether higher optical thickness is retrieved when the cloud is homogeneous or inhomogeneous. Or when the retrieval assumes a homogeneous or inhomogeneous cloud. Please rewrite.

p2, l30 ff.: "3D effects, which depends " -> which depend

p4, l17: "Wavelet"-> wavelet

p4, l23ff: "... fractional cloud has a fractional cloud cover fixed to 0.76 and a het-

erogeneity parameter equal to 1.12 if the heterogeneity parameter (optical standard deviation over the mean optical thickness) is computing including the zeros or 0.95 if it is computing only with the cloudy pixels." -> Sentence is not clear after "1.12", please rewrite.

p5, l2: "where I are" -> is

p5, l2: I think that the dots in the unit W.m-2.sr-1 are not AMT standard.

p6, l4: "differences are important according to the viewing direction." -> "differences highly depend on the viewing direction."

p6, l23: "from every viewing angles"-> "from all viewing angles"

p6, l30: "lower than the ones ..." -> "lower than the one ..." (cloud albedo)

p6, l32: "coherent"-> "consistent"

p7, l32: "shadows area" -> "shadow area"

p8, l3: "7x7km" -> "7kmx7km resolution"

p8, l4ff: text refers to Figure 4a and Figure 4b, but (a) and (b) is not included in Figure 4.

p8, l11: "appear differently according to ... " -> "appear differently depending on"

p8, l17: "At 670 nm, the polarized reflectance in the shadow part is only slightly enhanced by the molecular scattering but sufficiently compared to 865 nm." -> I do not understand what is meant by "sufficiently" in this sentence.

p8, l22: "no present" -> "not present"

p9, l3: "bias" -> "biases"

p9, l10: "much more important" -> "much larger"

p9, l32: Please define "Rayleigh pressure"

p10, l10: "polarized reflectances in function of the scattering angles ... " -> "polarized reflectances as function of the scattering angles ... "

p11, l8: "retrieve values" -> "retrieved values"

p11, l15: "In the case of the optical thickness and high solar illumination (SZA=20°), we obtain ..." -> "For high solar elevation (SZA=20°) the optical thickness retrieval yields ..."

p11, l17: "For POLDER, it leads to retrieve optical thicknesses underestimated by 10 or 35%" -> "For POLDER, the retrieved optical thicknesses are underestimated by 10 or 35% ..."

p11, l22: "cloud heterogeneities effects " -> "cloud heterogeneity effects"

p11, l26: What is meant with "negative polarization"?

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