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Comment

## ***Interactive comment on “Critical surface albedo and its implications to aerosol remote sensing” by F. C. Seidel and C. Popp***

**F. C. Seidel and C. Popp**

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### **Replies to Referee 3**

We are very grateful for the thoughtful reviewer comments, which helped to considerably improve the manuscript.

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## General Comments

**Comment 1** [...] *“I would also have preferred if realistic bidirectional reflectance distribution function (BRDF) models were used rather than the Lambertian approximation, although acknowledge that this would have increased the complexity of the study.”* [...]

**Reply** We appreciate the reviewer’s comment on the use of non-Lambertian surfaces and we will add a sentence in the last paragraph of the introduction summarizing the following reasoning. We have performed a purely theoretical analysis for a range of discrete spectral surface reflectance, or hemispherical-directional reflectance factor (HDRF) values. We think that taking into account non-Lambertian surfaces would complicate the interpretation of our results without much benefit. In addition, we are disinclined to introduce ‘real’ surface types, such as grass, water, vegetation, etc., because our results would be contingent on the inherent assumptions of the surface type’s BRDF. Instead, we believe that the AOD retrieval sensitivity as a function of continuous surface reflectance values (or albedo) provides more value to the reader. One can choose the reflectance value from any given BRDF at the corresponding scattering angle and find the AOD retrieval sensitivity for that reflectance value from our results. Technically, the BRDF would only change the spectral surface albedo  $a_\lambda$  in Eq. 5 from a scalar number to a vector containing a surface phase function as function of the scattering angle between the direction of the direct irradiance (sun’s position) and the viewing geometry.

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## Specific comments

**Comment 2** *“Abstract: “CSA is defined as the surface albedo, where the reflectance at top of atmosphere (TOA) does not depend on aerosol optical depth (AOD). ... We show that the CSA also depends on AOD” This appears to be a contradiction, and is a somewhat confusing pair of statements! It should be addressed. I suppose what you are really saying is that CSA is an idealised concept while in reality there is a range of surface”*

**Reply** We appreciate this comment very much because we recognise now that our text is somewhat confusing regarding the dependence of the CSA on AOD. We will clarify our definition of the CSA being the surface albedo, where two different AOD values have the same corresponding TOA reflectance. In our manuscript we have missed to add a note that the same does not have to be true also for a third AOD value. In fact, we found that the CSA changes with AOD because multiple CSA exist for different pairs of AOD values. Please see also our reply to comment 7 of Reviewer 1. Reviewer 3 points out correctly that we are using here an idealised concept, which enables us to derive the CSA with the partial derivative of the TOA reflectance with respect to AOD. In reality, the CSA is a range of surface albedo. We will take this point into account and make it more clear in the Abstract, the Methods as well as in the Conclusions.

**Comment 3** *“Page 7727, around line 25: You are missing the recent and relevant paper by Wells et al. (2012), which would fit well in this section.”*

**Reply** We will add Wells et al. (2012), which was published after we have submitted our manuscript to AMTD.

**Comment 4** *“Page 7730, line 10: As pointed out by the other reviewer, there is a contradiction between the text and table caption with respect to the dust model’s origin.”*

**Reply** We will correct the text, while the Table caption remains correct.

**Comment 5** *“Page 7731, lines 3-4: This relates to my point in the abstract. Is it not*

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*better to say rather that there is a range of conditions over which the retrieval solution will be degenerate? The lines not crossing at the same point really show that the CSA is an approximation which is not always valid, i.e. there does remain some sensitivity of TOA reflectance to changes in AOD, it is just very small. I suspect the range of albedo of crossing points of the lines in Figure 2 is smaller than the uncertainty of knowledge on surface albedo. Or do I not understand correctly what you are doing?"*

**Reply** Your comment is absolutely correct. We believe that our idealistic and theoretical approach is more comprehensible and easier to repeat than the realistic case with a range of surfaces with low sensitivities to AOD. In a next paper we could incorporate overall AOD retrieval uncertainties due to instrument, model, retrieval and other errors and compare it to the AOD retrieval sensitivity. See Seidel et al. (2008) for related results looking at AOD retrieval fidelity vs. signal to noise.

[Seidel et al.(2008)] Seidel, F., Schläpfer, D., Nieke, J., and Itten, K.: Sensor Performance Requirements for the Retrieval of Atmospheric Aerosols by Airborne Optical Remote Sensing, *Sensors*, 8, 1901–1914, doi:10.3390/s8031901, 2008.

**Comment 6** *"Page 7732, lines 2-4: You might note here that marine AOD over 0.2 is unlikely (e.g. Smirnov et al., 2011), which then is good news for AOD retrieval over ocean, as it suggests there will be sensitivity to AOD for typical conditions."*

**Reply** A good point, which we will adopt and cite the Smirnov et al. (2011) paper.

**Comment 7** *"Page 7733, section 3.1.3: This section would benefit from some cursory mention at least of BRDF effects. You note that the CSA is often higher for backward scattering geometries. Such geometries are also often where BRDF effects are strongest, e.g. the hotspot effect. So I would expect that the simulations might be less representative of reality for these conditions. Some comment on this in the paper would be helpful."*

**Reply** We will add comments on BRDF and mention that this theoretical study is intended to show the variability of the CSA as a function of various parameters. Please see also our reply to comment 1 above for more details.

**Comment 8** *“Page 7734, section 3.1.4: See previous comments about why it might be more meaningful to talk about an albedo range with minimal AOD sensitivity, rather than a distinct CSA.”*

**Reply** We completely agree with Referee 3 and we will rephrase the corresponding parts throughout the revised manuscript in order to be more precise.

**Comment 9** *“Page 7734, section 3.2.1: How do you ‘retrieve’ AOD in this case? Manually run 6S for a set of AOD and figure out which one corresponds to the TOA reflectance simulated with the ‘true’ albedo?”*

**Reply** We used the same look-up tables (LUTs) which we have prepared for this study (c.f. Sec. 2.2. and Tab. 1.). In these LUTs, the TOA reflectance (6S output) is stored as a function of different forward model parameters such as surface albedo, geometry etc. with a specific discrimination. In order to estimate the retrieval error (AOD ‘true’ minus AOD “retrieved”), the AOD ‘retrieved’ can be interpolated from the LUT. We have the ‘retrieved’ surface albedo (+/- 0.01 of the ‘true’ surface albedo), the TOA reflectance from the ‘true’ case remains the same for the ‘retrieved’ case such that the only unknown is the AOD ‘retrieved’ which we find by interpolating the LUT appropriately. We will add a description on our AOD ‘retrieval’ to Sec. 3.2.1. in the revised manuscript to clarify this.

**Comment 10** *“Page 7737, lines 7-8: see my comments about section 3.1.3 above, which is also relevant to mention here.”*

**Reply** We agree with Referee 3 and we will rephrase and extend these sentences in the revised manuscript in order to be more precise.

**Comment 11** *“Page 7737, line 16: It would be good to comment on deserts, also.”*

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**Reply** Good point. We will include a note on deserts in the revised manuscript. Generally, deserted surfaces are often quite close to the CSA which certainly also depends on wavelength, aerosol absorption, soil/surface type etc. The missing retrieval sensitivity, or strong influence of even small inaccuracies, is a main reason why AOD retrievals over deserts are especially challenging. We did not mention deserts in this particular line in conjunction with snow and clouds because the latter two usually have reflectances in the visible ( $< 0.7$ ) well above the CSA for absorbing aerosols (0.1 - 0.6). Therefore, snow and clouds are 'easy' targets for AOD retrievals of absorbing aerosols as long as the surface albedo is known well enough. This is not the case for desert surfaces with reflectance values (0.3 - 0.6) typically close to the CSA. Please see Figs. 8 a, c, d, and e).

**Comment 12** *"Page 7737, lines 22-27: This is a good point. Some retrieval algorithms such as the Oxford-RAL Aerosol and Clouds (ORAC) scheme take this approach, see e.g. Sayer et al. (2012). Surface reflectance is constrained based on the MODIS BRDF product, and the retrieval is performed as a simultaneous inversion from multiple wavelengths, so that channels are effectively weighted based on such partial derivatives (i.e. according to the actual information present in the channels). This methodology also directly produces the uncertainty estimates you mention. Another example of such a retrieval scheme is given by Govaerts et al. (2010). I would suggest these are worth mentioning in your conclusions, to show these ideas are possible in practice."*

**Reply** Thank you for this valuable comment. We will be happy to add those examples with the corresponding references.

**Comment 13** *"Finally, there is one obvious extension of this work which should be simple to do and, in my view, would make the manuscript much more useful. You have already simulated CSA for a range of different geometric conditions and aerosol types. You can also freely download e.g. MODIS data, which can give you global maps of surface albedo, together with viewing geometry, and AOD. Together with some simple assumptions about aerosol types, you could make some first-order maps of when and*

*where in the world we are likely to run into situations where we are near the CSA. Even with simple assumptions it would be a step forward which I don't believe we have now. Such a map would be useful for the aerosol remote sensing community. It would be interesting to see whether such regions correspond to those where different satellite datasets differ.*

*This should only really take the authors a day or two of work because they already have all of the complicated results from their simulations. I suggest creating seasonal maps of where conditions are such that satellites are within some threshold of the CSA. Maybe a colour scale which shows the absolute difference between surface albedo and CSA. Most satellite sensors are either in late morning or early afternoon orbits, so you could use the two MODIS sensors (Terra/Aqua) as representative examples. The wavelengths you have already calculated for would be good to show (although the MODIS albedo product does not have 412 nm, you could use the other two wavelengths). It may be that the pattern looks the same for different wavelengths and orbit times, in which case you'd only need to show one.*

*I don't know what the result would be, but it would be interesting and useful, and since the authors have already performed the more timeconsuming part of the analysis, should be a very easy extension. Please consider this."*

**Reply** We are very grateful to Referee 3 for this valuable suggestion. However, we believe that such a study would be beyond the scope of our theoretical work. It would deserve well more efforts and we think the results should be worth a full paper. To our knowledge, a quantitative and spatially complete as well as spectrally resolved global dataset of aerosol absorption is not available to the public. For completeness, the case of geostationary satellites should in our opinion also be treated in such a study, especially having future GEO satellites with improved sensor characteristics for aerosol remote sensing in mind (MTG, GEO-CAPE). Nevertheless, we will be happy to mention this idea in the concluding section because it will improve our manuscript by adding an interesting perspective.

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## Technical comments

**Comment 14** *“Page 7726, line 3: Remove comma after ‘albedo’.”*

**Reply** We will correct this sentence.

**Comment 15** *“Page 7727, line 1: ‘Many spaceborne sensors allow the retrieval of total vertical columnar...’”*

**Reply** We will correct this sentence.

**Comment 16** *“Page 7727, line 6: Delete the word ‘factor’.”*

**Reply** We will remove ‘factor’.

**Comment 17** *“Page 7727, line 8: I suggest deleting ‘(or reflectance)’ for simplicity, as typically radiance is what is measured. I would also suggest replacing ‘a correct’ with ‘an accurate’.”*

**Reply** We will correct this sentence.

**Comment 18** *“Page 7727, lines 9-10: I suggest replacing ‘the reflecting Earth’s surface’ with ‘reflection from the Earth’s surface’.”*

**Reply** We will correct this sentence.

**Comment 19** *“Page 7727, line 25: replace ‘could improve’ with ‘improved’.”*

**Reply** We will correct this sentence.

**Comment 20** *“Page 7730, lines 23-25: ‘In general, TOA reflectance increases with increasing AOD for darker surfaces and decreases with increasing AOD for brighter surfaces.’”*

**Reply** We will improve this sentence.

**Comment 21** *“Page 7730, lines 26-29: ‘At this particular surface albedo, the increase in TOA reflectance from aerosol scattering is balanced by the decrease in TOA re-*

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*flectance from aerosol absorption.”*

**Reply** We will improve this sentence.

**Comment 22** *“Page 7731, line 14: replace ‘relation revealed’ with ‘relationship revealed.’”*

**Reply** We will correct this sentence.

**Comment 23** *“Page 7731, line 17: ‘which fits the TOA reflectance well’”*

**Reply** We will improve this sentence.

**Comment 24** *“Page 7736, line 11: ‘to the studies mentioned above is’”*

**Reply** We will correct this sentence.

**Comment 25** *“Page 7736, line 12: ‘assume a linear relation’ or ‘assume a linear relationship’. Also, the word ‘reflectance’ is missing after ‘TOA’ here and on the next line.”*

**Reply** We will correct this sentence.

**Comment 26** *“Page 7737, line 5: delete comma after ‘although’”*

**Reply** We will correct this sentence.

**Comment 27** *“Page 7737, line 11: ‘the studies mentioned above’ or ‘the previously-mentioned studies’”*

**Reply** We will correct this sentence.

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Interactive comment on Atmos. Meas. Tech. Discuss., 4, 7725, 2011.

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