Reviewer # 1

Review on "*Aerosol direct radiative effect over clouds from a synergy of OMI and MODIS reflectances*" by de Graaf et al.

I had three major concerns/questions for the original manuscript. The first is about the anisotropy factor, the second is about why OMI and MODIS observed cloud reflectances differ significantly when their overpassing time is only 15 minutes away, and the last question is about the sampling rate of method described in this paper for deriving DRE of above cloud smoke. The authors have addressed these major concerns/questions carefully and thoroughly.

However, I still have a few minor questions and comments left. They have to be addressed before the manuscript can be accepted for publication.

- Even in the revised manuscript, the definition of the DRE derived from the combined OMI-MODIS observation is still not clear and precise enough. As pointed out in *[Zhang et al.*, 2016], the all-sky DRE of aerosol is defined as $DRE_{all-sky} = f_c\overline{DRE_{cloudy}} + (1 - f_c)\overline{DRE_{clear}}$, where f_c is the cloud fraction, $\overline{DRE_{cloudy}}$ and $\overline{DRE_{clear}}$ is the averaged cloudy-sky and clear-sky DRE, respectively. Take a hypothetical example. Assuming that we have an OMI-MODIS pixel with a cloud fraction $f_c = 0.5$. The $\overline{DRE_{cloudy}}$ due to above-cloud smoke is 40 Wm^{-2} and $\overline{DRE_{clear}}$ is 1 Wm^{-2}. Which of the following values does the method described in this paper reports? 1) $\overline{DRE_{cloudy}}$=40 Wm^{-2}, 2) $f_c\overline{DRE_{cloudy}}$=0.5*40 Wm^{-2}=20 Wm^{-2}, or 3) $DRE_{all-sky}$=20 Wm^{-2} +0.5*1 Wm^{-2}=20.5 Wm^{-2}. This question should be clarified early in the paper, for example, in Section 2. It is an important question because the answers will help the readers understand precisely the meaning of the DRE from this study, as well as how to compare the DRE from this study with previous ones such as *[Zhang et al.*, 2016].
- Another question, which is related to the question above, is about how to scale the OMI spectrum to match MODIS observation. If I understand correctly, the reflectance of a cloudy pixel observed by OMI can be decomposed into $R_{OMI} = f_{c,OMI}R_{cld+aer} + (1 - f_{c,OMI})R_{clr}$. Similarly, the reflectance observed by MODIS is $R_{MODIS} =$

$f_{c,MODIS}R_{cld+aer} + (1 - f_{c,MODIS})R_{clr}$. It is not clear to me what the "scaling" in section 3.5 means. Is the "scaling" intended to match R_{OMI} and R_{MODIS}? What is the "scaling" factor and what is its physical meaning? These questions are important, and they need to be clarified in the context of the above equations.

- Page 2 line 20, there are a few noteworthy previous studies on the DRE of above cloud aerosols that might deserve being cited here, e.g., *[Peters et al.*, 2011; *Feng and Christopher*, 2015; *Zhang et al.*, 2016] *and a very recent study [Kacenelenbogen et al.*, 2019]. Some discussion should be made about the originality and significance of the current study w.r.t. these previous studies as well as those from the leading author.
- Page 4, equation (3), again what is the exact definition of DRE_{aer} here? See my first and second questions above.
- Page 7, similarly, what is the DRE derived from *SCIAMACHY?* Is it $\overline{DRE_{cloudy}}$, $f_c\overline{DRE_{cloudy}}$ or $DRE_{all-sky}$?
- Page 10, line3, "*and 0.35 in the red pixel*". Should it be "*and 0.35 in the blue pixel*"
- Also, what does FRESCO stand for?

Feng, N., and S. A. Christopher (2015), Measurement-based estimates of direct radiative effects of absorbing aerosols above clouds, Journal of Geophysical Research-Atmospheres, *120*(14), 2015JD023252–n/a, doi:10.1002/2015JD023252.

Kacenelenbogen, M. S. et al. (2019), Estimations of global shortwave direct aerosol radiative effects above opaque water clouds using a combination of A-Train satellite sensors, *Atmospheric Chemistry and Physics*, *19*(7), 4933–4962, doi:10.5194/acp-19-4933-2019.

Peters, K., J. Quaas, and N. Bellouin (2011), Effects of absorbing aerosols in cloudy skies: a satellite study over the Atlantic Ocean, *Atmos. Chem. Phys*, *11*, 1393–1404.

Zhang, Z., K. Meyer, H. Yu, S. Platnick, P. Colarco, Z. Liu, and L. Oreopoulos (2016), Shortwave direct radiative effects of above-cloud aerosols over global oceans derived from 8 years of CALIOP and MODIS observations, *Atmospheric Chemistry and Physics*, *16*(5), 2877–2900, doi:10.5194/acp-16-2877-2016.

Answers to Reviewer #1 Review on "Aerosol direct radiative effect over clouds from a synergy of OMI and MODIS reflectances" by de Graaf et al.

The reviewer is thanked for the appreciation of the manuscript and the previous changes, which were very helpful and improved the manuscripts considerably.

Below the additional questioned are answered:

- The first question was about the all-sky DRE. This is something that is not considered in the manuscript. It should be clear from the title and the text from the beginning that only cloud scenes are considered in this manuscript. The all-sky DRE is complicated to derive from observations, since the clouds are very diverse and have very many effects on the DRE, even when 3D effects and cloud edge problems are not considered. The suggested computation by the reviewer is an approximation of the all-sky DRE that is only valid for homogenous cloud fields. It was now made even more clear in the manuscript that the derived DRE from OMI is valid only for sufficiently clouded scenes, where sufficiently was defined as FRESCO CF > 0.3, as stated in the text before. Also added was a warning that this should not be used to derive an all-sky DRE using the independent pixel approximation, as the OMI footprints are too large for that. The added section is:

  Note that the more general all-sky direct radiative effect of aerosols in both clear and cloudy scenes is often derived as $\mathrm{DRE}_{\mathrm{all\ sky}} = f_{\mathrm{cld}} \cdot \mathrm{DRE}_{\mathrm{cld}} + (1 - f_{\mathrm{cld}}) \cdot \mathrm{DRE}_{\mathrm{clear}}$. *Here,* $\mathrm{DRE}_{\mathrm{cld}}$ *is the direct radiative effect of all aerosols in a completely overcast atmosphere,* $\mathrm{DRE}_{\mathrm{clear}}$ *the direct radiative effect of all aerosols in a cloud-free (Rayleigh) atmosphere, and* f_{cld} *is the fraction of clouds. However, the validity of this equation, known as the independent pixel approximation, is dependent on pixel size and cloud homogeneity. The cloud fraction* f_{cld} *is the fraction of an area where clouds appear with similar radiative properties. This may be true for satellites with sufficiently small pixels and homogenous cloud fields. However, in this paper the aerosol DRE is derived from OMI, which has a relatively large footprint. For OMI an* effective *cloud fraction is derived using the Fast Retrieval Scheme for Clouds from the Oxygen-A band (FRESCO) algorithm, using the* O_2-O_2 *absorption band at 477 nm and the DRE is derived for OMI pixels with an FRESCO CF > 0.3 to ensure sufficiently clouded scenes. The effective cloud fraction differs from the geometric cloud fraction, in that it is radiatively equivalent to the geometrial cloud fraction and cloud optical thickness of the scene, assuming complete cloud coverage. Therefore, COT and cloud droplet effective radius (CER) are retrieved assuming a completely clouded scene. Then, the aerosol DRE is computed using those cloud parameters again assuming complete cloud coverage. Although this is common for satellite cloud products, it should be understood that the OMI aerosol DRE dataset is not equivalent to the* $\mathrm{DRE}_{\mathrm{cld}}$. *A large part of the scenes with either small (geometrical) cloud fraction or small cloud optical thickness are not considered by selecting only scenes with FRESCO CF > 0.3. These scenes will have a small positive or negative aerosol DRE, as aerosol scattering dominates over dark surfaces. Therefore the average OMI aerosol DRE in this paper is higher than the average true cloud or all-sky aerosol DRE. However, the dataset can be used to validate simulations of the* *aerosol DRE or other observational datasets where also scenes with CF > 0.3 are selected.*

- The second question is about the combination of OMI and MODIS reflectances. Again, the reviewer decomposes the reflectance in a cloudy and cloud-free part, adding them. However, radiatively this can only be done when the cloud is homogenous. In general, each cloud part with different COT and CER has to be added separtely. However, the discussion is not about how to add cloud-free and cloud reflectances. In general, the MODIS reflectances aggregated over the OMI footprint will yield a different average reflectance than the OMI reflectance for that footprint, due to differences in instrument response functions, uncertainties in viewing directions, calibration errors, changing scenes during the instrument overpasses, etc. Therefore, the reflectances have to be matched, which can be done since the spectra overlap. In general, the difference was found to be small, since both instruments are well calibrated. However, we found that especially for broken cloud fields the difference can be significant. Therefore, the physical significance of the 'scaling factor' is the uncertainty of the combination of observations, including all the effects mentioned above. However, the only significant effect is the change in reflectance due to cloud fraction difference. And this effect is already quantified in section 4.3 (Accuracy assessment) in the manuscript, where the accuracy of the cloud reflectance simulation is assessed. This uncertanty includes both the uncertainty of the measurement (combination) and the simulation.
- The references have been added.
- The aerosol DRE over clouds is defined in section 2 and valid for any selected OMI cloud pixel. It is not to be mistaken with any of the parameters defined by the reviewer.
- The same as above holds for the aerosol DRE for SCIAMACHY cloud pixels.
- Correct. This was changed.
- The acronym FRESCO was defined at first use.

Answers to Reviewer # 2

I reviewed a previous version of this manuscript. My main issues with the previous version were (1) discussion of the anisotropy factor B and related uncertainty; (2) choice of a threshold UVAI=0 as a baseline for the uncertainty calculations; and (3) the fairly simplistic nature of the 2016/2017 data analysis (mentioning ORACLES but not using the data). In this revision the authors have expanded the discussion of (1) and (2), which I appreciate, and added MODIS and OMI above-cloud satellite time series for (3) while noting that the comparison with ORACLES data is better suited for a separate paper (which I hope they do). This makes it more convincing, in my view, than the previous submission.

The reviewer is thanked for the constructive criticism and helpful comments that have helped improve the manuscript. The remaining questions are answered below.

As a result I do not have technical objections to the publication of this manuscript, although the other reviewer (Z. Zhang) is more of an expert in the forcing aspect than I am, so I would defer to their judgment.

I have a few minor comments, but otherwise find the manuscript acceptable for publication after technical corrections. I would be happy to review these corrections if the Editor feels it would be helpful, although I do not think it is necessary, provided the other reviewer is satisfied.

Previous comment on POLDER: the authors had cited a paper in preparation which compared the OMI/MODIS results against POLDER. I'd suggested the authors provide the results here or remove the reference, since we can't see the results otherwise (given it's a paper which has not been submitted yet). They replied that they have added the information and also removed the citation. It's not clear to me where the information about this comparison has been added, as it doesn't seem to be in the original section; there is a brief mention in section 4.2 of POLDER but that seems to be it? Mentioning just in case something was inadvertently omitted, but I think it is ok as-is.

The POLDER reference has been added since it is now available as a discussion paper.

Page 7 line 27: a reference for the MODIS sensor should be added (one is already provided for the other satellite instruments used). I don't have a particular strong feeling about which, but Salmonson et al (1989) is often used:
https://ieeexplore.ieee.org/document/20292

The reference was added.

Page 10 line 2: Acronym FRESCO needs to be defined at first use.

This was added.

Page 21 line 4: Acronym AERONET needs to be defined at first use. Also, state which version you are using and provide a reference. It should be the current version 3, with citation Giles et al (2019): https://www.atmos-meas-tech.net/12/169/2019/amt-12-169-2019-discussion.html Also define the data level being used. I see this is level 1.5 rather than the standard level 2; after checking the AERONET website I see level 2 is not available yet for Ascension Island in 2017. It is worth mentioning the difference between levels and stating why level 1.5 is used here.

The acronym was defined at first use. The used version was version 2, the level 1.5, for the reason mentioned by the reviewer. Version 3 is also available, but it showed rather different behaviour than the V2 data and was not used. This is mentioned in the manuscript and a reference was added.

Page 22 lines 30-32: VIIRS and OMPS acronyms should be defined at first use. Also, there is more than just SNPP now, NOAA20 (formerly JPSS1) launched in late 2017.

The acronyms was expanded and the NOAA20 reference added.

Section 4.3.3 and more generally: in this section (and elsewhere) the authors say "error" often. I think a lot of these times, they really mean "uncertainty". For example, page 19 line 9 I think the authors mean the "uncertainty" in the DRE retrievals, not the error, since we don't have a truth to compare to. If possible it would also be good for the authors to clarify whether the estimates they provide in the paper refer to typical levels of uncertainty (e.g. 1-sigma), maximum likely uncertainty, or similar.

Correct. The term error was replaced by 'uncertainty' where appropriate and total error by accuracy. The uncertainty estimates are specified.