Response to comment of Anonymous Referee #1 on "DARCLOS: a cloud shadow detection algorithm for TROPOMI" by Victor Trees et al.

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We thank the reviewer for his/her careful reading and for the comments and suggestions, which have improved the manuscript. Below, we give in *blue italic* the reviewer's comment, in black our response, in *black italic* copied text from the manuscript and in *red italic* the changed or new text in the manuscript.

This paper discusses the DARCLOS cloud shadow detection algorithm, and applies it to TROPOMI radiances. The algorithm is clearly explained and the paper is well written, and should be published after minor revisions.

General comments

The DARCLOS algorithm relies on a longitude-latitude monthly climatology of cloud heights. The authors need to discuss the errors associated with the climatology that is applied in the paper. What are the standard deviations (state 1 or 2 sigma) of the cloud heights compared to cloud height validation data? The authors should discuss this by reference to the content in the Koelemeijer et al., 2001 and Wang et al., 2008 papers.

DARCLOS does not use a climatology of cloud heights, but the TROPOMI L2 FRESCO cloud height (see line 145). We have increased the cloud top height to calculate the PCSF, resulting in an overestimation of the shadowed area in the PCSF. In the ACSF and SCSF, the overestimation is removed using the SCNLER-DLER contrast.

It is confusing to read on page 6, line 145 that "hc is the 145 FRESCO cloud height:, while on page 20, line 430 that "With a future implementation of the effective cloud fraction from FRESCO which uses the TROPOMI DLER climatology..". On page 6, line 145, add a phrase "applied using the DLER climatology (discussed below)" to tell the reader FRESCO currently uses DLER, and that the cloud fraction portion of FRESCO uses LER climatology (page 20, line 429, "The surface albedo input for the effective cloud fraction calculation in the NO2 product is the LER climatology").

We agree with the reviewer that this sentence could cause confusion. The current version is not using DLER climatology, but LER climatology. A future version will use the DLER climatology. We have changed the sentence as follows:

line 430: *With a future implementation of the effective cloud fraction from FRESCO which uses the TROPOMI DLER climatology at a* $0.125° \times 0.125°$ *latitude-longitude grid instead (see Sect. 2.2.2), the accuracy of the CF, PCSF and ACSF is expected to further increase.* –> "*With a future implementation of the TROPOMI DLER climatology, which uses a* $0.125° \times 0.125°$ *latitude-longitude grid instead (see Sect. 2.2.2), in the effective cloud fraction algorithm, the accuracy of the CF, PCSF and ACSF is expected to further increase.*"

On page 21, line 433, it is stated that "DARCLOS has not been tested at regions covered by ice and/or snow, nor at sunglint geometries over ocean." Over the ocean of course a longitude-latitude climatology of clear ocean is problematic since glint reflectance is dependent on the 10m ocean windspeed. For a given ocean scene, however, it is possible to create a PDF of radiances, from which a cloud radiance threshold can be calculated which can be used to identify clouds. Did you try such a technique in the development of DARCLOS? It would be useful in the Conclusions section to briefly discuss how you will treat ocean glint scenes in future developments.

We did not try adjusting the surface albedo climatology for FRESCO. Indeed, with an ocean surface reflectance calculation, the surface albedo could potentially be adjusted. However, the glint and a cloud can possibly be equally bright at some locations. We speculate that after a glint correction an overcorrection could take place such that some clouds would be interpreted as cloud-free. This could potentially be solved using a multi-wavelength approach, however, because this can be considered a problem to solve in the FRESCO algorithm instead of in the DARCLOS algorithm, we do not further elobarate on this in the paper. We added the following sentence to this paragraph:

line 437: "*With future potential improvements of FRESCO above glint and snow/ice regions, DARCLOS could be tested above glint and snow/ice regions. Then, the DLER for snow/ice conditions (see Tilstra, 2022) should be employed in DARCLOS, and possibly an ocean surface reflectance calculation can help distinguishing between clouds and the glint.*"

Mention in the Conclusions if / how ACSF and SCSF data will be stored in TROPOMI data files. Will this be done in already existing files on in new separate data files?

We added the following sentence to the conclusion:

line 495: "*The shadow flags of DARCLOS are planned for implementation in the TROPOMI L2 SCNLER product.*"

Specific comments

The term "in close constellation with TROPOMI" could be reworded to "in close proximity to TROPOMI".

We changed "in close constellation with" to "in close proximity to" everywhere in the text as suggested.

The term "raise" is a bit confusing since equation (1) "raises, alters the height of" h in proportion to hc-hsfc, while the algorithm "raises, identifies" PCSF to ACSF values. "Raise" is used with different meanings in the text. To lessen the confusion, it is suggested to revise the following phrases:

We do not agree that the usage of the verb 'raise' is confusing, because from the subject of the sentence (the flags) we think that the meaning of the verb 'raise' is clear. Instead of replacing the verb 'raise' in the context of raising flags, we replaced the verb 'raise' for 'increase' in the context of increasing the cloud height. We adjusted the text as follows:
line 147: "*we have introduced the safety margin C which raises the cloud*" –> "*we have introduced the safety margin C which increases the cloud height*"

Page 1, line 6, revise to "DARCLOS raises (identifies) potential cloud shadow flags"
See previous comment.

Page 5, line 128, revise to "with a raised (identified) cloud flag (CF) and.."
See previous comment.

Page 6, line 147 to "which assigns the cloud height h proportional to hc -hsfc."
See previous comment.

Page 7, line 171 to "in which PCSFs are to be raised (identified), based on"
See previous comment.

Equation (1) has a C factor, set to 0.5. How was the value of 0.5 determined? How did the F1 scores vary as C varied? I did not see a discussion of C in Section 4, while line 148 on page 6 implies that this topic would be discussed in Section 4.
Line 148 should not imply that this topic would be discussed in Section 4, because the reference to Section 4 (placed after 'false negative shadow detections') was meant to direct the reader to the explanation of the definition of a false negative shadow detection, rather than to an analysis of the convergence of PCSF omission error versus safety factor C. We do not add the lower values of C yielding higher PCSF omission errors to this paper, because that could confuse the reader. As explained on line 149, with $C = 0.5$ the number of underestimated maximum potential shadow extents (the omission error of the PCSF) converged to a minimum. We changed the following sentence:
line 147: "*We set $C = 0.5$, for which the number of false negative shadow detections (see Sect. 4) resulting from underestimated maximum potential shadow extents converged to a minimum.*" –> "*We set $C = 0.5$, for which the number of false negative shadow detections (i.e. the omission error of the PCSF, see Sect. 4) resulting from underestimated maximum potential shadow extents converged to a minimum.*"

Page 2, line 35. How did the ground pixels change from 7.2 x 3.6 to 5.6 x 3.6 on 6 August 2019? The sentence implies that the actual physical dimensions changed. Please clarify.
We added a footnote to the sentence on line 35 with the following text:
"*The radiance co-addition time reduced from 1080 to 840 ms starting in orbit 9388. This resulted in a decrease of the minimal*

along-track sampling distance from 7 km at nadir to 5.5 km at nadir (see Sect. 14 of Ludewig et al., 2020)."

Page 7, line 107. The phrase "inside but near the edges of the cloud pixel" was not clear in my first reading. The word "inside" makes sense if the cloud pixel is larger than the TROPOMI pixel size. An additional sentence is suggested to clarify the situation.

We rephrased this sentence as follows:

line 166: "*Moreover, the unknown true horizontal and vertical cloud extents are projected inside but near the edges of the cloud pixel.*" –> "*Moreover, the actual projections of the unknown true horizontal and vertical cloud extents are located inside but near the edges of the cloud pixel.*"

Page 7, line 172. The term "cloud-free" was at first confusing with regard to point Q in Figure 3, since point Q is shaded, but point Q is not untouched by cloud effects (it is in fact the cloud shadow). There are some readers who consider a "cloud-free" pixel to be a pixel not perturbed in radiance value by the presence of a cloud – which can yield a radiance enhancement (point O) or a radiance dimming (the point Q cloud shadow). An additional sentence can be added to clarify and lessen any confusion.

We added the following words:

line 172: "*... we flag all the cloud-free ground pixels within or intersected by the triangle* OPQ." –> "*... we flag all the cloud-free ground pixels (i.e. for which no CF is raised) within or intersected by the triangle* OPQ."

Page 9, line 231. Explain the rationale for using the "the 10% lowest SCNLER measurements".

We changed the following sentence as follows:

line 231: "*In the DLER algorithm, the 10% lowest SCNLER measurements in the seasonal grid cell were used, and measurements containing aerosols or clouds were excluded (see Tilstra, 2021).*" –> "*In the DLER algorithm, an initial cloud screening was performed on the basis of NPP-VIIRS cloud information. After that, the 10% lowest SCNLER measurements in the seasonal grid cell were used which serves as a second-stage cloud filter, and measurements containing aerosols were excluded (see Tilstra, 2022).*"

Page 9,. Line 241. Specify what Adler is.

We changed the description as follows:

line 241: "*The division by* A_{DLER}" –> "*The division by* A_{DLER} *(the value of the DLER)* "

Page 10, line 250 – Page 11, line 283. Consider moving these lines to Page 12, line 290. I found this text to be out of place, and perhaps better placed in an organizational sense in the next Section.

We have introduced a new subsection at this location in the paper:

2.2.4. Rationale behind the SCNLER-DLER contrast parameter

We have changed the first sentence of this subsection as follows:

line 250: "*Here, we demonstrate the behavior of the variables used in Eqs. (11) to (13) with an example measurement.*" –> "*Here, we demonstrate the behavior of the variables in Eqs. (11) to (13) which determine the SCNLER-DLER contrast parameter* Γ *with an example measurement.*"

Page 11, Figure 5. It would be helpful for the reader to have lmax identified in the figure caption for both panels.

λ_{max} is not indicated in Figure 5, because λ_{max} may vary per pixel. Indeed, this happens not to be the case for the pixels in Figure 5, as can be seen in Figure 6a (all land pixels have $\lambda_{\text{max}} = 772$ nm, and all ocean pixels have $\lambda_{\text{max}} = 402$ nm), however, indicating λ_{max} would suggest that λ_{max} does not vary per pixel, which may cause confusion. Therefore, we decided to keep Figure 5 as is.

Page 13, line 302. Revise to "Only a few shadows of small isolated clouds are detected by the ACSF".

We changed the text as suggested:

line 310: "*Only few shadows of small isolated clouds are detected by with the ACSF.*" –> "*Only a few shadows of small isolated clouds are detected by the ACSF.*"

Page 13, line 312. Replace "temporarily" by "mischaracterized". You don't know if the error is due to a temporal problem, so "mischaracterized" is suggested.

We adjusted the text as follows:

line 312: "*by a temporarily bright surface*" –> "*by bright surfaces*"

References

Ludewig, A., Kleipool, Q., Bartstra, R., Landzaat, R., Leloux, J., Loots, E., Meijering, P., van der Plas, E., Rozemeijer, N., Vonk, F., and Veefkind, P.: In-flight calibration results of the TROPOMI payload on board the Sentinel-5 Precursor satellite, Atmospheric Measurement Techniques, 13, 3561–3580, https://doi.org/https://doi.org/10.5194/amt-13-3561-2020, 2020.

Tilstra, L. G.: TROPOMI ATBD of the directionally dependent surface Lambertian-equivalent reflectivity, KNMI Report S5P-KNMI-L3-0301-RP, Issue 1.2.0, https://www.temis.nl/surface/albedo/tropomi_ler.php, [Online; accessed 7-February-2022], 2022.