Replies to RC2 – from 3rd May

Dear Referee,

we would like to thank you for taking the time to provide us with those constructive comments in a very direct and efficient way. We strongly believe that the revised article will benefit a lot after following your suggestions. Please see our replies to your comments below.

General comments

Although the detailed comparison is useful to understand the impact of the changes depending on the cloud situation, I think that the paper would be easier to read when some parts could be shortened and some plots would be combined.

We agree that the article should become shorter and we will follow the referee's suggestions in this effort.

Specifically, for the correlation plots and histograms it is not clear why they are shown or what the reader should learn from them. A qualitative description and an interpretation in the context of the problem would be helpful.

Several comments (both in the "general comments" and "detailed comments" sections) refer to the scatter plots and histograms, by asking why are those important. We believe that scatter plots and histograms are both valuable tools in data analysis. For instance, if the new scheme introduces any outliers, we would be able to spot them with the scatter plot and histogram analysis. Scatter plots are useful for identifying patterns, trends, and correlations between the "old" and "new" scheme. They allow us to see the overall distribution of data points and any clustering or dispersion. Histograms of the differences between "old" and "new" schemes are effective for identifying patterns such as symmetry, skewness, and multimodality in the new data. In the revised version, we will make the plots more condense and informative (e.g., by adding the cloudiness information) and improve their interpretation/explanation in the text.

The grouping in the categories A-K is also difficult to follow for me, the respective parameters between the groups do not show a clear correlation. Please consider discussion the observations more along the groups and combining the barplots.

From several comments understood that the classification into the A-K categories creates more confusion than providing qualitative interpretation of the new results. The main points that we wanted to communicate to the reader through those plots are: (a) The zero absolute differences are in general present under fully cloudy conditions with a cloud fraction higher than 0.8, which shows that the parameters remain unchanged with the new scheme under fully cloudy conditions (i.e., CF>80%). (b) The more negative differences are primarily present in clear sky conditions, which means that the new scheme results into statistically larger cloud fractions under clear sky conditions (i.e., CF<20%). (c) The positive differences are more relevant for the cloudy conditions. In the revised version, we will consider to remove the barplots (along with table 3) from the article and communicate the aforementioned statements through the updated scatter plots and histograms.

Detailed comments

C1 – OK, we will shorten the abstract.

C2 – The word "frequently" will be replaced and the sentence will become "The ground pixel footprints of the involved spectral bands should be fully aligned but when they are not, a special treatment is required within the operational algorithms."

C3 – It is actually the UVIS (BD3 and BD4) which we were naming UV/VIS in this article. In the revised version, when we refer to spectral range we will use "UV/VIS" and when we refer to TROPOMI spectrometer we will use "UVIS" according to the L1B documentation.

C4 – Yes, we refer to the Westernmost footprint of each scanline. We will change the term from "first UV detector pixel" to "first (westernmost) TROPOMI ground pixel in UVIS grid".

C5 – The comment probably refers to Table 1 and not Table 2. We will update the table so that it becomes clear that TROPOMI contains 4 spectrometers but each spectrometer is split into 2 bands. Relevant text will be also updated such that there are no inconsistencies of the terminology in the article.

C6 – Thank you very much for the reference. In the cloud retrieval algorithm, we only use BD3, BD4 (from the UVIS spectrometer) and BD6 (from the NIR spectrometer). In this article, we would like to emphasize the mis-registration between two different spectrometers (i.e., UVIS and NIR) and not between two bands within the same spectrometer. We actually consider this mis-registration of two bands negligible in our cloud retrieval algorithm. In the revised article, we will correct the statement that the mis-registration is only caused because of using different spectrometers and add the suggested reference.

C7 – We would like to point out that the mis-alignment is not a fixed number (e.g., 1.5 km shift to the West or East) but analogous to the footprint size coverage on Earth. But the way it is phrased causes confusion and thus in the revised version we will only keep the reference to the spatial resolution in the across-track direction.

C8 – We were referring to the UVIS spectrometer. In the revised version, when we refer to spectral range we will use "UV/VIS" and when we refer to TROPOMI spectrometer we will use "UVIS" according to the L1B documentation.

C9 – We will add that λ is the symbol for the wavelength.

C10 – We prefer to keep only the retrieved cloud parameters in the table to clearly separate them from the other variables used, which originate from other sources like an external climatology or auxiliary datasets.

C11 – We will remove the "Among others," because the S5P L2 CLOUD product is only based on OCRA/ROCINN algorithm. For NO2, there is also the FRESCO algorithm which is used for providing the cloud parameters as input for the trace gas AMF calculations, but FRESCO outputs are not included in the official TROPOMI L2 cloud product.

C12 – We will make clear that we refer to the ground pixel at nadir and the ground pixel footprints at the edges of the swath.

C13 – We will rephrase to: "… it becomes larger towards the edges of the swath due to the Earth's curvature and the instrument large swath angle."

C14 – We will rephrase to: "The so-called binning factors are selected to optimize the signal-to-noise ratio per pixel with the aim to minimize the difference in ground pixel size in across-track direction."

C15 – We will rephrase to: "At the edges of the swath the binning factor is reduced from 2 to 1 in order to keep the ground pixel size at a reasonable value. Due to optical limitations of the instrument and the curvature of the Earth, the ground pixel size at the edges of the swath is about 15 km (KNMI, 2022)."

C16 – Only between BD3 and BD6. We will remove the reference to TROPOMI BD4 from the sentence in line 109.

C17 – The upper panel of Figure 2 refers to the weights (based on the KNMI LUT) from the source BD3 to the target BD6, which is relevant for OCRA. The lower panel refers to the mapping weights from the source BD6 to the target BD3, which is relevant for ROCINN. To our view, both figures need to be included since both mapping directions are necessary within the OCRA/ROCINN algorithm. Mainly the differences are noticeable at the West and East part of the swath (before and after the binning factor change).

C18 – No, this is how we calculate a cloud fraction from VIIRS. VIIRS uses 4 bins/classes: "confidently cloudy", "probably cloudy", "confidently clear" and "probably clear". Then we construct a cloud fraction defined as the ratio of the "confidently cloudy" class over the summation of all classes.

C19 – In the efforts of shortening the article, we will consider to decrease the length of section 3.3.

C20 – Even if the binning factor change happens at the east part of the swath too, we observe (by looking to the upper panel of figure 2) that the "special" case of having three BD3 source pixels contributing to the BD6 target pixel occurs only at pixel #19. We can also visually understand this "special" case if we look in figure 1: the red 19^{th} BD6 footprint has an overlap with the three blue 20^{th}, 21^{st} and 22^{nd} BD3 footprints. We will make clear this point in the revised text.

C21 – In order to decrease the size of those figures, we will apply a reduction in the vertical spacing of the "source" and "target". The vertical lines are only for illustration purposes to create an effect like the grid of the actual millimeter paper. If there is no grid in the illustration, the reader might have more difficulty to see the vertical alignment of the pixels in the three plots for "imager", "source band" and "target band". Combining all figures will cause an inconsistency problem to our view, as for each equation we have a respective figure clarifying which are the known variables and which the unknown depending on the case (i.e., 2 source pixels contributors, 1 source pixel contributor, 3 source pixel contributors from UVIS to NIR for the cloud fraction and the reverse direction for cloud top height and the other ROCINN parameters).

C22 – We will indicate in the caption that the horizontal lines are expected to be overlapping as the mis-registration is in the across-track direction. We would prefer not to combine the two plots as they refer to different cases and equations.

C23 – We will define H in Section 3.3.

C24 – They are named from 0 to 448 for BD6 and from 0 to 450 for BD3, from West to East. They are defined in the beginning of Section 3 (lines 86-87).

C25 – Yes, because they are just describing a linear regression model (i.e., *alpha* is the regression slope and *beta* the regression intercept). For each scanline, one *alpha-beta* pair is calculated and therefore, it would not make sense to include any numbers of those parameters in the article.

C26 – Yes, because the denominator in the weight calculation (see Eq. 6 and 13) becomes 0. We will rephrase it to: "… when the neighboring VIIRS pixels contain equal values, leading to numerical errors at the weight calculations".

C27 – From fig 11, the reader can learn the following: (a) visually see that the CTH TROPOMI NIR (original parameter) does not contain values in the first magenta ground pixel. (b) notice that the co-registered CTH TROPOMI UV/VIS and original CTH TROPOMI NIR maps are very similar, demonstrating that the new co-registration scheme does not introduce inconsistencies. (c) Compare visually the CTH TROPOMI UV/VIS and CTH VIIRS UV/VIS and observe that the cloud top height values can be very different in absolute numbers but still the weight calculation can be performed smoothly and the new co-registration scheme will not alter the original cloud structures.

C28 – We want to show that the new co-registration will not change the overall statistics (mean, standard deviation and correlation coefficient) for all the retrieved cloud parameters or introduce outliers. However, in our efforts to shorten the length of the article, we will make the content of those figures more condensed and informative (in line to our reply in the general comments).

C29 – The sentence should be rephrased to "... the new scheme is only applicable up to a certain latitude and the pixels around the poles are co-registered with the fallback." The applicability of the new scheme up to a certain latitude is a limitation simply due to the lack of VIIRS cloud optical thickness data in those latitudes. The VIIRS cloud optical thickness originates from the CloudDCOMP (Daytime Cloud Optical and Microphysical Properties) EDR (see Sention 3.3.), whereas the VIIRS cloud fraction and cloud top height originate from other EDRs where valid data points appear in high latitudes.

C30 – We want to show that the new co-registration will not change the overall statistics (mean, standard deviation and correlation coefficient) or introduce outliers. However, in our efforts to shorten the length of the article, we will make the content of those figures more condensed and informative (in line to our reply in the general comments).

C31 – Yes, we have checked this. And indeed, the reader can see it in figure 18. We will rephrase it to: "The differences are exactly zero when VIIRS data are not available because the co-registration is done with the fallback.".

C32 – The differences are split into those 10 symmetric bins around the “zero difference bin” covering the whole accepted range of each parameter. The binning is not done equidistantly because the data points are not equally populated around the median. Thus, a more arbitrary selection of the binning has been performed to ensure that each bin contains “enough pixels” and none of the bins is under-sampled. Nevertheless, in our efforts to shorten the length of the article we will re-consider if figures 22-25 (along with table 3) are very necessary or can be removed from the article.

C33 – We believe that the global maps difference plots for the co-registered parameters should not be removed as they demonstrate that (a) the differences are not systematically present in certain regions but rather spread everywhere, (b) there is not a latitudinal dependence and (c) viewing geometry dependencies are not present. However, in our efforts to shorten the length of the article we will consider to place the global maps for one or two parameters in the main article and move the other maps to the Appendix (e.g., keep figure 18 and move figures 19-21 to the Appendix).

C34 – In our efforts to shorten the length of the article we will question if figures 22-25 are very necessary or can be removed. Please see reply to C32.

C35 – We will rephrase that the gap is reduced by one ground pixel and include a reference why are those gaps present.

C36 – We will rename it to “first (westernmost) TROPOMI ground pixels in the UVIS grid”.

C37 – The major improvements with the new co-registration appear at cloud edges and therefore we would like to highlight some example cases. The overall statistics do not change as can be seen from the scatter plots and histograms (figures 13-17).

C38 – We will follow the suggestion.

C39 – We will follow the suggestion.

C40 – In the efforts of shortening the article, we will consider to decrease the length of this section.

C41 – We refer to the forward model used for the training of ROCINN neural networks (since ROCINN was earlier in the article introduced as the operational cloud algorithm for TROPOMI). The text refers to the comparison figures 35-37 against CALIPSO, where the labels “TROPOMI new” and “TROPOMI old” have been used in the figure legends. The forward model for ROCINN is LIDORT; there is a reference and a short description in Section 2.

C42 – The TROPOMI operational cloud parameters are those stored in the S5P Level-2 CLOUD product, which can be accessed from the Copernicus Data Space Ecosystem search tool (https://dataspace.copernicus.eu/). Any other auxiliary cloud data (e.g. FRESCO used in NO2) should not be referred here in our view, as it can be confusing for the TROPOMI users.

C42 – Thank you for the comment and recommendation. We will try to follow this suggestion for the revised version of the article.

Technical Comments

General: We will adjust the acronyms and correct the spelling of inconsistent terminology.

We will apply the corrections T1, T4, T5, T11, T12, T13, T14, T15, T16, T17, T18, T19, T20, T22, T23, as suggested.

T2 – We will rephrase to: “The TROPOMI operational cloud algorithms OCRA/ROCINN (Loyola et al., 2018) have a long-standing heritage and have already been applied operationally to a large number…”

T3 – We will rephrase to: “… in near-real-time (NRT) the large data volume of TROPOMI.”

T6 – In the revised version, when we refer to spectral range we will use “UV/VIS” and when we refer to TROPOMI spectrometer we will use “UVIS” according to the L1B documentation. See replies to relevant previous comments.

T7 – UV will be corrected to UVIS.

T8 – We will remove the word “From”.

T9 – We will replace the word “well” with “successfully”.

T10 – In the revised version, when we refer to spectral range we will use “UV/VIS” and when we refer to TROPOMI spectrometer we will use “UVIS” according to the L1B documentation. See replies to relevant previous comments.

T21 – We will rephrase it to: “The old scheme is applied for co-registering the OCRA CF when the VIIRS CF at both UV/VIS and NIR bands are equal to 1.”

T24 – We will make clear that only one of the (co-)authors is a member of the editorial board of Atmospheric Measurement Techniques.

References: We will approach ESA and the authors of this document to add it in the Sentinel 5P document library.

Figures: We will follow the suggestion and adapt the colors for people with red-green blindness.