AMT-2022-122 Author's comment to RC1 by Referee #3 (Miriam Latsch et al.)

Cloud parameters (cloud fraction and cloud height) from different cloud retrieval algorithms for Sentinel-5 Precursor (S5P) TROPOMI are compared in scatter diagrams, latitude-longitude maps, tabular intercomparisons, and daily across-track intercomparisons. The variety of graphs of the intercomparisons are insightful and allows the reader to assess adequately the general aspects of the intercomparisons in a quantitative manner.

We thank Referee #3 for the comments. Detailed responses to the comments can be found below.

Main points:

This paper compares the different cloud products such as cloud fraction and cloud height, but goes no further than the intercomparisons. The intercomparisons need to be placed into context to the uncertainties of the primary recommended cloud fraction and cloud height TROPOMI data products. Are particular cloud products recommended by the TROPOMI science team? If so, which data products? If not, this should be stated. What are the cloud fraction and cloud height uncertainties of the primary products (if recommended), and how do these uncertainties relate to the spread in the intercomparisons presented in this paper?

A recommendation for a specific cloud product is not the subject of this paper and would also not make sense as each application has its own requirements for the optimum cloud product. Therefore, we aim at giving an overview of the existing TROPOMI cloud products and highlight their differences but are not judging which product is best to use.

The formal mission product requirements for the CLOUD (OCRA/ROCINN) retrieval algorithm state that the uncertainty due to systematic effects is 20% for cloud fraction, cloud height, cloud albedo and cloud optical thickness, and the uncertainty due to random effects is 0.05 for cloud fraction and cloud albedo, 0.5 km for cloud height, and 10 for cloud optical thickness (from the recent validation report ROCVR by Lambert et al., 2022).

In order to address the point of the reviewer, we renamed the Section 4 to "Summary and Conclusions" and added a paragraph in Line 639 to give a better overview and summary about the TROPOMI cloud products:
"Several different cloud products are included in the S5p operational lv2 data, and they differ in their definition and typical application. The OCRA a priori cloud fraction operates in the UV/VIS spectral region and is used as input for the ROCINN CRB and CAL models, which operate in the NIR spectral region. For global statistics, using the cloud fraction from OCRA or from the ROCINN products will not make a big difference. For individual measurements, particularly over snow and ice cover, it is recommended to use the ROCINN CRB and CAL cloud fractions instead of the OCRA a priori cloud fraction. FRESCO provides an effective cloud fraction retrieved from top-of-atmosphere reflectances, assuming an optically thick Lambertian cloud with a fixed albedo of 0.8. This approach is useful for trace gas retrievals, e.g., for ozone. FRESCO retrieved in the O_2 A-band becomes sensitive to systematic uncertainties of the surface albedo with strong viewing angle dependence, especially over forests. Due to the large difference between

the O_2 A-band and the NO_2 retrieval window and the misalignment between the TROPOMI ground pixel view of the VIS and NIR bands, the cloud fraction from the TROPOMI NO_2 product has been developed. It is suitable for NO_2 trace gas retrievals because the cloud fraction is retrieved from the NO_2 fitting window in the UV/VIS spectral region at 440 nm. The O2-O2 algorithm uses measurements from the O2-O2 (O_4) absorption window at 477 nm and assumes a fixed cloud albedo of 0.8. Although a similar model as the one in FRESCO is used, the O2-O2 cloud product is more sensitive to lower clouds and to aerosols due to the application of O2-O2 collision-induced absorption. It also provides continuity with data from the OMI mission. The MICRU algorithm is optimized for low cloud fractions smaller than 0.2 and is preferred for pixels over water with sun glint due to the explicit treatment of sun glint. The VIIRS cloud fraction is a geometric cloud fraction retrieved from a 4-level cloud mask with cloud probability. It does not depend on cloud optical thickness as strongly as an effective cloud fraction and thus, it shows a good performance for selecting completely cloud-free scenes. Therefore, it is useable for cloud screening by TROPOMI products, e.g., the methane processor, to identify cloud free scenes for processing."

As an additional request, Figure 16 cloud fraction curves of various algorithms have a spread of 0.2 in the cloud fraction values. Other instruments also generate cloud fractions. What are the uncertainties associated with e.g. MODIS, and how do the MODIS uncertainties compare to the TROPOMI spread in the cloud products? This sort of additional information will enhance the value of the paper. It is not requested to do MODIS – TROPOMI data intercomparisons, but a several- sentence discussion of typical MODIS cloud data product uncertainties would be informative.

The reviewer suggests a comparison of the spread of TROPOMI cloud fractions with uncertainties from MODIS cloud fractions. This would make sense if cloud fractions were universal and well-defined quantities. However, as discussed in the manuscript, the various cloud fractions are based on different assumptions and definitions, and therefore vary in their values. This is not the same as the uncertainty of the values from for example measurement noise, shadowing, or uncertainties in the surface reflectance used which all add additional variability to the data. We therefore do not see the benefit of comparing the differences between different cloud fraction types to uncertainties of MODIS cloud products.

Several paragraphs need to be added to the paper to address these requests before publication.

Minor points

My copy of the paper does not have indented paragraphs. Should line 49 and subsequent paragraphs be indented?

The formatting of the preprint followed the template provided by AMT. The final manuscript will be typeset by the journal and will adhere to all style rules.

The Figure 5 and Figure 11 numbers and x axis labels associated with the small boxes are too small to be readable. Please increase the font size.

The numbers and the axis labels of these plots in the manuscript and the supplement have been enlarged.

Line 586 has a blank line. Please correct this typo.

This has been corrected.

Criteria

1. Does the paper address relevant scientific questions within the scope of AMT? Yes, intercomparisons of data products fall within the scope of AMT.
2. Does the paper present novel concepts, ideas, tools, or data? The intercomparisons are useful and straightforward. Novel concepts are not introduced by the paper.
3. Are substantial conclusions reached? The intended outcomes of the intercomparisons are discussed in an adequate manner.
4. Are the scientific methods and assumptions valid and clearly outlined? Yes
5. Are the results sufficient to support the interpretations and conclusions? Yes
6. Is the description of experiments and calculations sufficiently complete and precise to allow their reproduction by fellow scientists (traceability of results)? Yes
7. Do the authors give proper credit to related work and clearly indicate their own new/original contribution? Yes
8. Does the title clearly reflect the contents of the paper? Yes
9. Does the abstract provide a concise and complete summary? Yes
10. Is the overall presentation well-structured and clear? Yes
11. Is the language fluent and precise? Yes.
12. Are mathematical formulae, symbols, abbreviations, and units correctly defined and used? Yes.
13. Should any parts of the paper (text, formulae, figures, tables) be clarified, reduced, combined, or eliminated? The intercomparisons need to placed into context (related to) the uncertainties of the primary TROPOMI and/or other instrument (e.g. MODIS) cloud data products used by the research community. See Main Points above.
14. Are the number and quality of references appropriate? Referencing of the various algorithms is adequate.
15. Is the amount and quality of supplementary material appropriate? Yes

Thank you for this overview and your feedback.

References

Lambert, J.-C., Keppens A., Compernolle S., Eichmann K.-U., de Graaf M., Hubert D., Langerock B., Ludewig A., Sha M. K., Verhoelst T., Wagner T., Ahn C., Argyrouli A., Balis D., Chan K. L., De Smedt I., Eskes H., Fjæraa A. M., Garane K., Gleason J. F., Goutail F., Granville J., Hedelt P., Heue K.-P., Jaross G., Kleipool Q., Koukouli M.-E., Lorente Delgado A., Lutz R., Michailidis K., Nanda S., Niemeijer S., Pazmiño A., Pinardi G., Pommereau J.-P., Richter A., Rozemeijer N., Sneep M., Stein Zweers D., Theys N., Tilstra G., Torres O., Valks P., van Geffen J., Vigouroux C., Wang P., and Weber M.: Quarterly Validation Report of the Copernicus Sentinel-5 Precursor Operational Data Products #15: April 2018 – May 2022, S5P MPC Routine Operations Consolidated Validation Report series, S5P-MPC-IASB-ROCVR-15.01.00-20220713, issue #15, version 15.01.00, 212 pp., https://s5p-mpc-vdaf.aeronomie.be/ProjectDir/reports//pdf/S5P-MPC-IASB-ROCVR-15.01.00_20220713_signed.pdf, 13 July 2022.