Response to interactive comments from Referee #2

We gratefully thank the reviewer for the careful reading of our manuscript and for the very constructive comments. Below the reviewer's comments are given in italic bold font. Our responses to the comments and how the comments have been addressed in the manuscript are shown in roman font.

The quantities directly affected by 3d cloud effects would be the retrieved cloud fraction and cloud height.

These quantities are generally used for calculating NO_2 AMFs, and, as far as I understand, this should not be changed according to the authors.

But then it is essential to first check how far the cloud retrievals are affected by 3D effects before analysing the effects on trace gases.

For instance, a cloud shadow causes lower reflectance. This might actually be dealt with in the existing algorithms if negative cloud fractions would be allowed. This way it might be actually quite simple to account for cloud shadow effects without introducing new concepts/quantities like CSF.

Also other 3d effects (clouds in neighboring pixels) will affect the cloud fraction and cloud height retrieved based on IPA. It would be interesting to see to which extent these "wrong" CF/CH parameters do the NO_2 AMF correction intrinsically (such as aerosol effects being partly accounted for by the cloud algorithms yielding higher CF and lower CH than "reality").

In this study, the 3D effects of NO_2 retrieval are discussed based on the classic NO_2 retrieval approach, which applied the cloud correction to the AMF calculation only for partly cloudy scene (the retrieved cloud fraction is larger than 0), otherwise, the scene is treated as cloud-free. The approach mentioned in the reviewer's comment, which uses the unrealistic cloud properties (negative CF), is not the standard approach. In addition, the cloud fractions are confined to [0,1] in the current TROPOMI cloud products (Loyola et al., 2018; van Geffen et al., 2021).

On the other hand, this approach can be added in the "Mitigation" part, which is one of possible way to improve the current NO_2 AMF calculation in the cloud shadow, called "AMF using extended cloud retrievals".

I would thus like the authors to add an analysis of 3D effects on the cloud products first. The further mitigation strategy might be different if 3D effects could already be accounted for by e.g. negative cloud fractions. In any case, the mitigation strategies cannot be discussed without knowledge on the effect of 3D cloud structures on the standard cloud products themselves.

We do not agree to add “an analysis of 3D effects on cloud products”, since the main focus in the study is analysing the 3D effects on the NO_2 retrieval, and the cloud products used for cloud correction in the NO_2 retrieval are based on a simple cloud mode and obtain the effective cloud properties (CF, CH). The accuracy of cloud retrieval does not link to the accuracy of cloud correction, especially for the nearly cloud free scene, which is the main concern for the NO_2 retrieval.

We add a series of Figures (Figure 1) in Appendix to give the examples of cloud and NO_2 retrieval for 1D cloud cases, which show that the FRESCO retrieval usually is closer to the true cloud height, but the NO_2 AMFs using the O_2-O_2 cloud correction often show better agreement with the true AMF, especially for the high cloud cases. Thus, we believe that the analysis of 3D effects on cloud products is not a relevant topic in this paper. In addition, an example of extended cloud retrievals in the cloud shadow is included in the section “AMF using extended cloud retrievals”.

Minor comments:

Page 1, Line 2: "generally implement Lambertian cloud models": This is not true, see for instance OCRA/ROCINN.
The sentence has been rephrased to: “generally implement a simple cloud model”

Page 1, Line 3: "photon path length corrections": to my understanding, the cloud algorithms interprete the measured O2 or O4 absorption in terms of a cloud height. This should be stated here.
This has been stated after:

The latter relies on measurements of the oxygen collision pair (O_2-O_2) absorption at 477 nm or on the oxygen A-band around 760 nm to determine an effective cloud height.

Page 2, line 6: "amount of the trace gas along the average path": this sounds like the average path could be calculated and then linked to the amount of trace gas. It is rather the average absorption along light paths.
This has been rephrased to: “the integrated trace gas concentration along the light path”

Page 2, line 19: "A simplified Lambertian cloud model is generally used": This is not true, see for instance OCRA/ROCINN.
The sentence has been rephrased to:

“A simple cloud model is generally used, which treats cloud as a Lambertian surface or a scattering layer, relying on the concepts of cloud fraction, cloud top albedo and cloud top pressure(Acarreta et al., 2004; Loyola et al., 2018; Wang et al., 2008).”

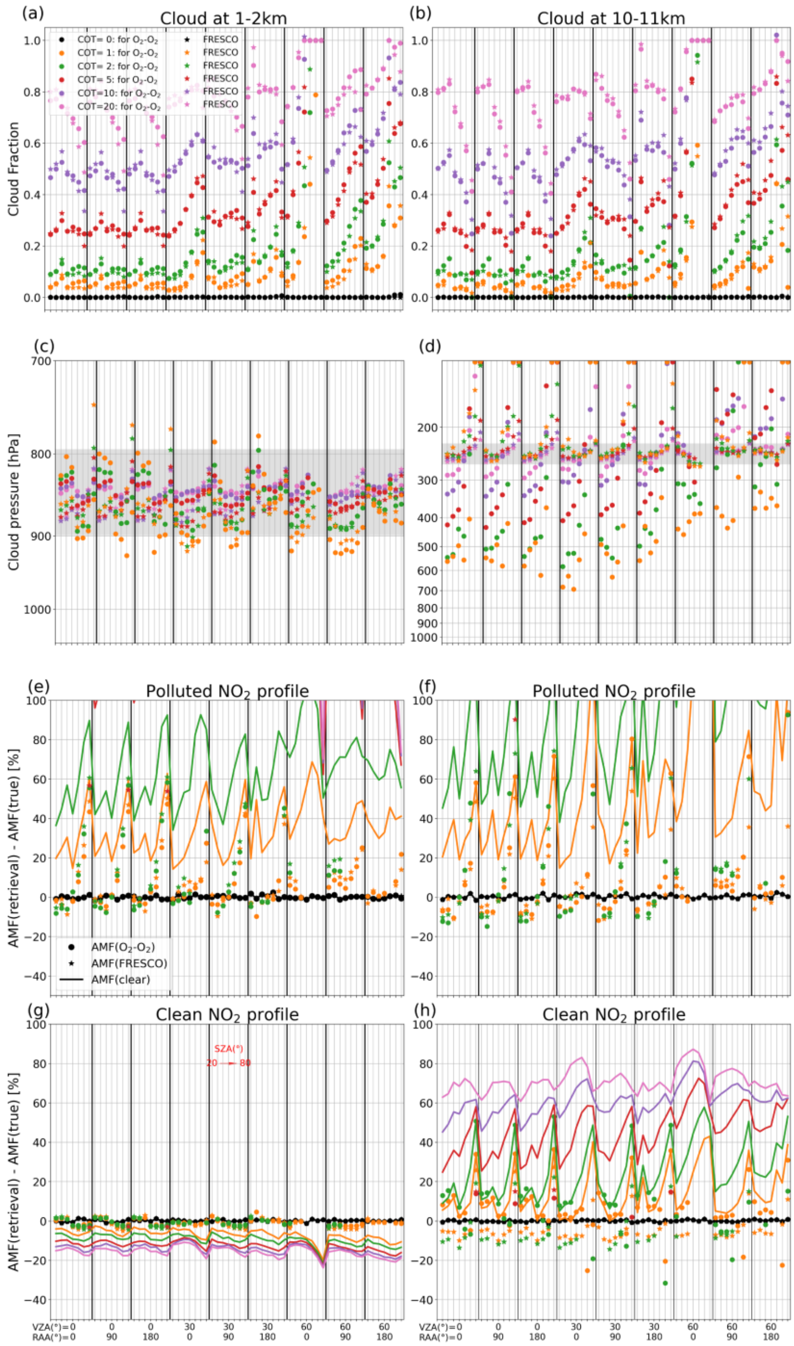

Figure 1: Examples of cloud and NO_2 retrieval for 1D cloud scenes, discussed in Section 2.5, with 1-2 km (left) and 10-11 km (right) cloud height. (a) and (b) show O_2-O_2 and FRESCO cloud fraction retrievals, (c) and (d) are the cloud pressure retrieval from O_2-O_2 and FRESCO cloud algorithms, the grey regions indicate the true cloud layer. (e)-(h) compare the bias of the NO_2 AMF retrievals using cloud correction based on O_2-O_2 and FRESCO cloud products, as well as the retrieval without cloud correction, for polluted (e)/(f) and clean (g)/(h) condition. The cloud correction is applied when the pixels with CF_w less than 50%. The x-axis represents the cases with different geometries. A variety of colors represent the cases with different cloud optical thickness.

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