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Atmospheric Measurement Techniques Discussions

Interactive comment on "Absolute calibration of the colour index and O_4 absorption derived from Multi-AXis (MAX-) DOAS measurements and their application to a standardised cloud classification algorithm" *by* Thomas Wagner et al.

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Reply to Anonymous Referee #1

General comments:

* This papers presents a continuation and improvement of the cloud-screening scheme presented in Wagner et al. 2014. The different calibration procedures enhance the usability of their cloudclassification scheme. However, the paper assumes a very detailed knowledge of concepts presented in the 2014 paper. It could be helpful if some concept are re-introduced or quickly summarised in the current paper. For some of the calibra-

tion/threshold procedures discussed by the author, the added value remains unclear.

Author reply: We thank the reviewer for his/her positive assessment of or manuscript. We are especially thankful for many very good suggestions. We addressed almost all of the points raised by the reviewer as outlined in detail below.

Specific remarks:

* For the reader, it would be good to see the direct impact of the proposed new calibration scheme on the cloud-classification scheme as presented in Fig.14 in Wagner et al. 2014. As some steps in the flowchart are not possible/advised using the new method, how does this affect the different sky conditions that can be distinguished?

Author reply: We added a new figure (Fig. 9, similar to Fig. 14 in Wagner et al. (2014)) and a new table (Table 1), which describe the classification scheme and summarise the changes for the individual decisions. We also added a new figure (Fig. 14) showing the effect of the new thresholds on the individual classification results.

* p3: When referring to the old wavelengths used (p3 and figures further), the author sometimes refer to 420nm, and sometimes to 440nm. This needs to me harmonised.

Author reply: We changed 420 nm to 440 nm in several parts of the manuscript.

* p3 l28: The authors define the calibrated CI as proportionally to CImeas. Are there instances when an additional constant offset is expected (CIcal=CImeas*β + constant), and how does this affect the calibration?

Author reply: An additional offset is only expected in cases of instrumental problems (e.g. wrong offset or dark current correction, or a non-linear response of the detector). However, except for very low signals (e.g. at high SZA) or cases with a strong oversaturation of the detector, these offsets should be very small. Moreover, oversaturated spectra could be easily identified by increased residuals of the spectral analysis.' We added this information to the text.

* p4 l34: The calibration procedure is a bit hidden in the text. It would be easier for the reader if it would be a bit more separated from the previous text, and the different steps more clearly itemised.

Author reply: We inserted a new sub-section '2.1 Calibration procedure' and structured the individual steps of the calibration procedure with alphabetic characters.

* p4 l35: The term "simulated minimum" should be defined better, also in the corresponding figure. To what optical depth does the minimum belong?

Author reply: We added the following information to the text in section 2 (at the discussion of Fig. 2): 'The minimum values are derived from a polynomial fit to the simulated minimum CI for different cloud optical depths as shown in Fig. 1. The polynomial expressions as well as the tabulated values of of the minimum CI are provided in Table 2 and Table A1 in the appendix.'

* p4 l35: This simulated minimum values that are needed for the calibration should also be tabulated in Table A1, so the reader can easily reproduce the calibration procedure, without having to run his own radiative-transfer simulation.

Author reply: We added polynomial expressions as well as the tabulated values of the minimum SZA, which are provided in Table 2 and Table A1 in the appendix.

* p5 l4: It should be noted that for sites with predominantly clear skies, an accumulation point will also be present, but at higher CI values, indicating clear skies.

Author reply: We added the following information at the end of section 2: 'In extreme cases, an accumulation point might even exist for CI representing clear sky conditions (if also the AOD stays constant over an extended time period). In such cases, clear sky measurement might be identified by visual inspection and be removed before the frequency distribution is calculated.'

* p5 l8: "after cloud sky data were removed": Does the author mean: after removing non-cloudy data?

Author reply: Yes, many thanks! The text is changed to '. . .after the clear sky data were removed'

* p5: It is at this point of the paper unclear what the added value is of the O4 measurements on the cloud classification, as this is not mentioned anywhere in the introduction. Especially since at p6 l16 the authors state that cloudy measurements need to be removed by the CI information, to perform a good O4 calibration.

Author reply: In the introduction of the original version of the manuscript it was already stated: 'From the other quantities, especially from the radiance and the absorption of the oxygen dimer O4 important additional information on cloud properties can be derived (e.g. on the presence of optically thick clouds or fog, see Wagner et al., 2014, Gielen et al., 2014; Wang et al., 2015).' We think that this information should be sufficient in the introduction. The removal of cloudy measurements (as stated at p6 l116 of the original mansucript) is only performed for the calibration of the O4 measurements. We are confident that the use of the O4 absorption in the cloud classification scheme will become more clear from the new Fig. 9.

* p5: I would like to see here again a definition of the calibration AMF, to make it clear for the reader: thus AMFcal=. . .. . .

Author reply: We modified the text to: 'To obtain the total O4 AMF of the measurement the O4 AMF of the FRS (AMFFRS) has to be added:

AMF = DAMF + AMF_FRS (5)

The determination of AMF_FRS constitutes the calibration of the O4 measurements:

AMF_cal,i = DAMF_i + const = DAMF_i + AMF_FRS (6)

Here DAMF_i indicates the differential O4 AMF derived from the spectral analysis of an individual measurement. AMF_cal,i indicates the corresponding calibrated O4 AMF.'

* p6 l26: As before, the simulated AMF values used for the calibration should be in

TableA1, allowing the reader to immediately follow the same procedure.

Author reply: The following information is added to the text: 'Polynomial expressions and tabulated values of the O4 AMF for AOD=0.2 (clear sky reference value) are provided in Table 2 and Table A1 in the appendix.'

* Fig9: Are the CI given here already calibrated? If so, it should be specified in the caption.

Author reply: The CI are already calibrated. We added this information to the figure caption.

* p8 l4: The meaning of the sentence "Note that the . . ." is unclear. Please rephrase.

Author reply: The sentence was changed to: 'Note that the CI for AOD of 0.85 at 390 nm represents the SZA dependent threshold value, see Tables 1 and A1.'

* p7 l33: Some more information on why AOD=0.75 is a good threshold would be useful. Is this still a good threshold for sites which are more polluted than Cabauw, and often experience high AOD values, which are not related to clouds?

Author reply: The threshold value used in the original version of the algorithm was chosen as a compromise to discriminate clear from cloudy observations (as e.g. identified from sky images). We found that the simulation results for AOD=0.75 (for 440 nm) fit best to the original threshold. However, it should be noted that cases with AOD>0.75 will not necessarily be classified as cloudy. If the temporal variation of the CI is smooth (TSI<threshold), they will be assigbed to the category 'clear sky with high aerosol load'. Thus the classification scheme will be also appropriate for locations with frequent occurrence of high aerosol loads. In the revised version of the manuscript, the flow chart of the classification scheme was added (new Fig. 9) to make the structure of the decisions more clear.

* Fig 10 and similar: These figures in my opinion do not give a good idea on the comparison between the old and new method. In Fig10 a very big difference is seen

between the new method and the old, but no further explanation is given as to where these differences come from, or whether the this means an improvement in the classification of clouds or the opposite. I would like to see figures which give a better qualitative and quantitative comparison between the old and new method: are there more misclassifications, are some conditions no longer present, etc.

Author reply: We replaced figures 10 – 13 by the new figure 14, which provides a detailed and quantitative comparison of the individual classification results obtained from the old and new classification schemes. (it should be noted that in the old Fig. 10 an error occurred in the legend: the black line represented the AERONET results and not the classification results of our algorithm. Thus the differences between the different versions of the classification scheme are much smaller than indicated by the wrong legend of the original version of Fig. 10.

* p8 l31: A visual representation of the TSI and threshold would be beneficial to the reader. Furthermore, a definition or formula for the TSI should be given.

Author reply: We added a new figure (Fig. 11) to the revised version. In this figure the diurnal variation of the CI and the derived TSI are shown for a selected day. We also changed the definition of the TSI to make it independent from the time difference of the individual measurements. Thus the new TSI becomes a more universal indicator of the temporal variation of the sky condition. The comparison of the old and new definitions of the TSI are compared in Fig. 11, and good agreement was found.

* p9 l18: The spread is calculated using the minimum and maximum CI in a scan. What happens if there are strong outliers, do these need to be removed first, or do they not impact the procedure strongly?

Author reply: In principle, outliers could affect the CI and thus also the spread of the CI. However, such outliers are usually very rare. They could e.g. be caused by an oversaturation of the detector. Oversaturated spectra can be easily identified by an increased fit residual of the spectral analysis. We added this information to the text at the beginning of sction 2 (see also our reply to the reviewer comment to p3 l28 above).

* FigA2: Caption: 'ange' should be 'angle'

Author reply: Corrected

* p9 l28: Where does the threshold of 0.14 come from? And are cases with optical depths > 6 not already identified by the CI value itself? It remains a bit unclear what exactly the added value is of the CI spread in the end given the restrictions discussed by the authors.

Author reply: We added the following information to the text: 'But we keep the original threshold value of 0.14 (see table 1), because according to Fig. 12 it still seems to be a good compromise to discriminate clouds and aerosols.' The old Fig. A2 was moved to the main text (as Fig. 12).

Besides the identification of cases with high aerosol load, the spread of the CI can also be used for the identification of clouds at low SZA, when identification by the absolute value of the CI fails (see Wang et al., 2015). We added this information at the beginning of section 4.3.

* p10 sect4.3.1: The author end by noting that the layer height makes it difficult to distinguish between clouds and aerosols. Can multiple scattering in clouds be identified in the O4 DSCDs, and in this way be used to distinguish between optically thick clouds and aerosols?

Author reply: Yes, using the O4 absorption makes it possible to distinguish between optically thick clouds and aerosols. And this possibility for the identification of optically thick clouds is already used in our classification scheme (see e.g. new Fig. 9). However, the problem still remains for the distinction of optically thin clouds and aerosols.

* p10 l21: The use of this value of AOD=0.2 should have already been discussed on p6 l26. What is the impact of choosing a different AOD value. Will this value of AOD=0.2 be too big for very clean sites (e.g. Jungfraujoch/Antartica)?

Author reply: The choice of the AOD values for the clear sky reference is not critical, because the threshold values are adapted to the chosen clear sky reference values. For Antarctica, however, the impact of the high surface albedo has to be considered, and new thershold values have to be used. These aspects are discussed in detail in section 5.5.

* p10 l22: The authors talk of a constant threshold for the O4 AMF, but in the table they give a polynomial expression for the threshold? Again, a visual representation for an example day, of the full data set, of the O4 AMF calibration and threshold would be beneficial.

Author reply: We added a new figure (Fig. 13) to the manuscript. It shows the diurnal variation of the calibrated O4 AMF and the corresponding threshold value for a selected day. To make the application of the threshold for the O4 AMF consistent with the procedure for the other quantities, we changed the order of the calculation steps: First a constant threshold value (0.85) is added to the SZA dependent clear sky reference value. Then the measured O4 AMFs are compared to the corresponding SZA dependent threshold. The details are provided in the new Table 1.

* p10 sect4.4.1: Again, some information on what the added value of the radiance is would be good. Do you need information of the radiance/O4 for the detection of thick clouds. Are these not already identified by the absolute CI value? Also, in stead of radiance, 'signal' should be used both in the text and in the figures.

Author reply: We slightly modified the beginning of section 4.4.1 (now 5.2) to make the added value of the radiance more clear. The text is now: 'Optically thick clouds can be identified using the O4 absorption or the measured radiance (Wagner et al., 2014). Especially for long term measurements, the effect of instrumental degradation on the radiance is usually much weaker than for the retrieved O4 absorption (see e.g. Wang et al. 2015). However, as mentioned before, the calibration of the radiance requires more effort than the calibration of the CI and O4 absorption. In particular, measurements for days with constant and well known AOD are required (Wagner et al., 2015). Thus the updated version of the cloud classification scheme does not use the measured radiance for the detection of optically thick clouds, because such clouds can also be well identified by the O4 absorption observed in zenith direction. Nevertheless, especially for long term observations, the use of O4 observations for the detection of optically thick clouds might be strongly affected by instrumental degradation (Wang et al., 2015). For such cases it might still be useful to identify optically thick clouds based on the measured radiance. . ...'

We replaced 'radiance' by 'signal' in the figure and figure caption. However, we prefer not to change radiance to signal in the text, because in the introduction it was already mentioned: 'Here it should be noted that usually (MAX-) DOAS instruments are not radiometrically calibrated. Thus we use the term 'radiance' here in a broader sense also for the measured signal, e.g. expressed as counts per second.'

* Fig17: Also plot the lines using the other albedo value (as used in Fig15).

Author reply: We added the O4 results for an albedo of 0.05

* p13 l13: What if no measurements under clear sky conditions are available?

Author reply: Of course, if no measurements under clear sky conditions are available, the calibration of the O4 absorption can not be performed. However, It should be noted that for such conditions, MAX-DOAS measurements are anyhow strongly affected by the influence of the clouds, and no reliable profile inversions are possible. At the end of section 2 we added the following information: 'It should be noted that for measurements at locations with very low or very high cloud probability a larger time period than for our method might be needed to obtain a sufficient number of both cloudy and cloud-free measurements. In extreme cases, an accumulation point might even exist for CI representing clear sky conditions (if also the AOD stays constant over an extended time period). In such cases, clear sky measurement might be identified by visual inspection and be removed before the frequency distribution is calculated.'

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