

***Interactive comment on* “Simultaneous satellite observations of IO and BrO over Antarctica” by A. Schönhardt et al.**

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Referring to the Interactive Comment of Anonymous Referee #3 from 09 February 2012

We would like to thank Referee #3 for the review of our manuscript and the helpful comments. Most of the advice and requests have been used in order to revise and improve the article. In the following, all comments by the Referee are addressed in the sequence they were raised in the review. We hope that our explanations and changes to the manuscript fully answer the Referee's questions. The Referee's comments are printed in italic font, our answers and explanations are printed in usual black font as well as the original versions of the manuscript. New text passages for the revised version

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of the article are written in blue colour.

First, the "General comments" made by Referee #3 are addressed in Part 1. The "Specific comments" are answered in Part 2 and the "Technical corrections" in Part 3.

Part 1. Answers to the "General comments" of Referee #3

Comment 1

As mentioned above, the strength of the paper is based on the six year data set where particular distributions become visible "after suitable averaging steps" as the authors point out. It would be helpful if some more explanation on the choice of the averaging method could be included so that readers who are less familiar with statistical methods can better follow the benefits or possible disadvantages (?) of the chosen method versus other averaging methods.

Answer to Comment 1

We admit that the chosen phrasing in this case is actually misleading. No further steps than mentioned in the text were applied. Temporal averaging is performed and the addressed "suitable averaging steps" refers firstly to a sufficient temporal averaging in order to improve the signal-to-noise ratio and with this the resulting IO maps. The signal-to-noise ratio improves when averaging is applied, as long as noticeable statistical noise is present in the result. Secondly, the sequence of averaging should be addressed by the chosen phrasing, that first the IO results are averaged over calendar months and then over subsequent years, thereby retaining information about variation on the shorter time scale. In order to remove the misunderstanding in this sentence we

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have changed the wording in the following way.

Changes to the manuscript in Section 4

- Original version:
After suitable averaging steps, details on the spatial distribution and temporal variation of IO become visible.
- Revised version:
After [applying temporal averaging over suitable periods of time](#), details on the spatial distribution and temporal variation of IO become visible.

Comment 2

Section 6 would benefit greatly from a Figure that visualizes the IO-BrO differences.

Answer to Comment 2

The referee makes a good and understandable suggestion here. However, it is not readily possible to plot a meaningful difference between the IO and BrO amounts here. The column abundances between the two species are quite different (in order of magnitude) and additionally the background amount (stratospheric in the case of BrO) constitutes a fundamental difference between the two species. Therefore, the IO-BrO difference itself would not give good information. Of course it would be easier for the reader to have both information, IO and BrO, in one figure for direct comparison of the differences, which is difficult for lack of space. We hope that the reader can cope

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with the comparison between the two species and that the arrangement of IO and BrO shown in the same sequence and type of map facilitates a good comparison between the distributions.

Comment 3

The temperature dependence of the IO cross section is a very interesting and important study by itself, which might be worth a separate publication.

Answer to Comment 3

We gratefully take notice of the appreciation by Referee #3. We consider the cross section study as preliminary and as a complementary study to estimate the effect of a changing temperature on the IO column densities and on the fit quality. The fundamental behaviour of the temperature dependent absorption spectra is comparable to that known from a study on BrO cross sections published by Fleischmann et al. (2004). For obtaining full IO absorption reference spectra, for precise band fitting and for the determination of spectroscopic constants, a finer spectral resolution would be necessary than the one used in the reported measurements. A follow-up lab study to obtain reference spectra at appropriate resolution is needed to fully describe the temperature dependence of the IO absorption cross-section.

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Part 2. Addressing the "Specific Comments" from Referee #3

Comment 4

p.33658, In.12: What is the detection limit based on?

Answer to Comment 4

This question by the Referee is very helpful, as we have been too short in our explanations here. In addition, the paragraph misses a reference to an earlier publication, where the detection limit of the fundamental retrieval is also discussed.

In general, the retrieval faces a detection limit due to a combination of effects. The main influences determining the minimum detectable optical density are given by the photon shot noise and atmospheric influences which are not accounted for in the retrieval. The latter kind of influences consists of statistical as well as systematic effects (stray light influences, disregarded/unknown absorbers). The accuracy of the conversion from the minimum detectable optical density (OD_{\min}) to the detection limit for a certain trace gas additionally depends, e.g., on the surrounding air temperature. In a single measurement, the OD_{\min} is determined from the root-mean-square (*rms*) of the residual from the DOAS fitting results. While the statistical part of the effects is efficiently reduced by averaging over many spectra, part of the systematic effects remains unaffected by averaging. Some systematic effects (such as the temperature effect) can show a partly statistical behaviour, if the underlying cause itself is variable. The given numbers represent typical values, however, the precise detection limit and uncertainties of the IO results vary for individual measurements.

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Changes to the manuscript in Section 3

- Revised version:

The detection limit for single recordings lies around 7×10^{12} molec cm⁻² for the slant column, corresponding to a vertical column around 1.7×10^{12} molec cm⁻² over snow and ice, depending on the AMF. This detection limit is based on the determination of a minimum detectable optical density (OD_{\min}) which is obtained directly from the residual of the DOAS fitting result, as discussed in more detail by Schönhardt et al. (2008). The root-mean-square (*rms*) of the residual gives a measure for OD_{\min} . For the conversion to the detection limit in terms of a slant column amount, the absorption cross section of IO is applied. Therefore, the slant column detection limit is temperature dependent. The given numbers represent typical values, which vary between individual measurements. For a typical orbit, e.g., the single measurement *rms* and its standard deviation are $(1.9 \pm 0.5) \times 10^{-4}$ corresponding to an IO slant column detection limit of $(6.8 \pm 1.8) \times 10^{12}$ molec cm⁻². This detection limit is reduced by temporal averaging, as performed in this study.

Comment 5

p.33658, third paragraph: Is it possible to give some kind of AMF error estimate based on some typical Antarctic aerosol profiles? Or at least put a number range on the "small" AMF error?

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Answer to Comment 5

In this paragraph the wording was chosen somewhat qualitative and misses numbers for the "small" aerosol influence. This is changed in the revised version.

In the Antarctic, aerosol amounts are comparably low and have little impact on the visibility. Typically, aerosol optical thickness (AOT) remains below 0.05 and often below 0.03, as can be seen, e.g., by AERONET measurements (see also <http://aeronet.gsfc.nasa.gov/>). Shaw (1988) even speak of the "ultraclean air over Antarctica". AMF calculations with the radiative transfer code SCIATRAN were performed for these representative low AOT cases. By parameterizing the aerosol influence by the concept of visibility, a visibility of 50 km corresponds to an AOT of 0.08 if the aerosol is mixed in a boundary layer of 1 km height (Bäumer et al., 2008). For such a case, the AMF for IO changes by up to 5% in the SZA range up to 75°, for larger SZA the difference would rise up to around 10% depending on the input assumptions on the aerosol characteristics. For an SZA below 65° a slight increase of the AMF in the presence of aerosol takes place, while above this threshold, the AMF is somewhat reduced. The precise shape of the AMF change depends on the aerosol type, size distribution and on the altitude profile, and is therefore fairly variable. However, a visibility of 50 km is already on the high side for the Antarctic aerosol budget. In typical cases, the aerosol influence on the IO AMF in Antarctica will remain below the stated numbers.

In a different parameterization, using a boundary layer extinction profile for the aerosol content that adds up to an AOT of about 0.05, a similar picture is obtained, where the typical influence of aerosol on the AMF remains below 5% over most of the SZA range and below around 7.5% even for large SZA. For these calculations, the IO is assumed to be situated in a boundary layer of 1 km.

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Changes to the manuscript in Section 3

- Revised version:

Aerosols influence the sensitivity of the measurement and hence the AMF, however, treatment of aerosols has been neglected in the present case as Antarctic aerosol concentrations are fairly low. The aerosol optical thickness (AOT) in Antarctica typically remains well below 0.05 and often below 0.03 as can be seen, e.g., by AERONET measurements (see also <http://aeronet.gsfc.nasa.gov/>). Low aerosol amounts in Antarctica are also reported by Shaw (1988). Aerosol observations from space over snow and ice are more challenging than over the ocean or land, so a complete set of aerosol information for the time and space covered by the IO analysis is not readily available yet. Using an AOT of 0.05 and assuming all the aerosol to be situated in the boundary layer with the IO, the AMF for IO changes by less than 5% over most of the SZA range. In an alternative computation using a parameterization of the aerosol load by a visibility of 50 km, an AOT of about 0.08 is represented (Bäumer et al., 2008). Again, the influence on the AMF is 5% up to 75° SZA and would rise up to 10% for very large SZA. Antarctic aerosol abundances typically stay well below these amounts, so the influence on the AMF is usually even smaller. The precise aerosol influence depends on the aerosol characteristics (type, size distribution, altitude profile) as well as on the relative vertical location with respect to the IO, and is therefore variable. The calculations reported above represent rough estimations of the aerosol importance.

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Comment 6

p.33660, ln.2: Should it be "small amounts of IO above the detection limit" or "too much IO close to the detection limit"? Perhaps replace "amounts" with "number of spectra" or "SCD measurements"

Answer to Comment 6

Here, we want to point out the fact, that atmospheric amounts of IO are comparably small, and even when enhanced amounts are observed, these amounts are often close to the detection limit of SCIAMACHY. The detection limit itself varies with location, amount of averaging, solar zenith angle and other factors. The order of magnitude of reported atmospheric amounts of IO, especially when spread over an area as large as the satellite instruments' ground pixel, is challenging for space-based observations.

Changes to the manuscript in Section 4

- Original version:
Due to the comparably small amounts of IO close to the detection limit of the instrument (Schönhardt et al., 2008), it is necessary to average IO results over several weeks to months to create maps with sufficient data quality.
- Revised version of the manuscript:
[Due to the comparably small atmospheric amounts of IO, many of the IO measurements are close to the detection limit of the instrument \(Schönhardt et al., 2008\), making it necessary to average the IO results over several weeks to months to create maps with sufficient data quality.](#)

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Comment 7

p.33660, ln.19: Perhaps change "is more meaningful than" to "is more meaningful for this study than"

Answer to Comment 7

This is a suitable change to the text and has been adopted for the revised version.

Comment 8

Figs. 1,3,4, perhaps also 6: Should have an identical color scale/legend

Answer to Comment 8

Figures 1, 3, and 4 have been modified and use the same colour scale now. For Figure 6, the original scale has been retained, as we consider it more suitable for that kind of diagram.

Comment 9

Figs.4 and 6: Where do the negative VCDs come from? Could they be significant and if no, why are they not filtered out? Fig.8: It would help to be able to (better) identify

latitude. Also, it would help to either have the same red box in Fig. 4 or have the respective months included in Fig.8 with the same box.

Answer to Comment 9

- The IO retrieval applied in this study uses a reference background spectrum from SCIAMACHY nadir Earthshine measurements over the Pacific. Negative VCD values therefore indicate that the IO content in the respective observation is lower than in the Pacific reference region. The IO retrieval in the reference region has been checked to yield approximately zero IO columns if the retrieval is using a solar reference background spectrum. The Earthshine spectrum is used as reference background instead of a solar background as this is yielding better fitting quality which is crucial in the treatment of trace gases with small absorption optical depth. Negative column amounts either indicate lower IO amounts than in the reference region, or point at remaining features in the spectral signature of the retrieval which have not been fully accounted for and which might interfere with the trace gas absorption under investigation. As these regions might require further improvement of the IO retrieval, the negative VCD values are not removed from the final result. In general, negative values cannot be removed from the averaging process of a quantity subject to significant noise as otherwise, the results would be high biased.
- The colour of the grid lines has been changed to a darker colour and latitude values have been added to the sea ice maps.
- For the requested better comparison of the selected region (red box) the second option has been adopted for the revised version, i.e. the two maps of IO have been included in Fig. 8 and the same red box has been added. The two IO maps are mentioned in the text and figure caption now as Fig. 8 (c) and (d).

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Changes to the manuscript

- The following line has been added to the caption of Fig. 8:
For comparison, the IO maps for October (c) and November (d) have been repeated here from Fig. 4.
- The following changes have been made to the text of Section 7.3, p.33667, l.20ff: The left upper map in Fig. 8 shows the average sea ice cover for October (a), the right upper map for November (b), both averaged over the six year period from 2004 to 2009.
- The following changes have been made to the text of Section 7.3, p.33668, l.1ff: As an example, a closer view on the section between 0 and 10 E shall be taken (box area in Fig. 8). Here, going from October to November, a rise in IO concentrations and a decline in ice concentration is observed (cf. Fig. 8 (c) and (d) as well as overall time series in Fig. 4 for IO).

Part 3. Technical corrections proposed by Anonymous Referee #3

- *p.33662, In.12 "in dependence of longitude" instead of "the longitude"*
The article has been omitted in the revised version.
- *p.33667, In.27: already been reduced*
The change to passive tense has been accepted for the revised version.
- *Fig. 6: change y-axis label to Month/Year*
The change to the y-axis label has been included in the revised version.

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