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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Direct observation of two dimensional trace gas distribution with an airborne Imaging DOAS instrument" *by* K.-P. Heue et al.

K.-P. Heue et al.

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paper

The authors thank Alexander Cede for his helpful comments and advice.

General comments

Direct observations of two dimensional trace gas distribution with an airborne Imaging DOAS instrument8220; by K.-P. Heue et al. is an excellent manuscript describing design and performance of a new airborne imaging DOAS instrument (iDOAS), showing iDOAS measurements of NO_2 columns over South Africa. The paper fits perfectly into

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Interactive Discussion

Discussion Paper

the scope of ACP, reads well, and the quality of the figures is excellent. Besides a few minor modifications (see specific comments and technical corrections), I suggest those two changes in the paper:

1) Use vertical columns all through the paper

2) Compare to OMI instead of (or in addition to) SCIAMACHY

Ad 1)
The figures in the manuscript sometimes show vertical NO_2 columns (figures 1 and 12), sometimes iDOAS slant columns (figures 8 and 9), and sometimes iDOAS slant columns together with SCIAMACHY tropospheric slant columns (figures 10, 11, and 14). Since the authors have already done the work to determine the AMF for the iDOAS data (section 2.3, last paragraph), and the satellite data are also available as vertical columns, I don8216;t see the point of not converting everything to vertical columns. Then the paper is more consistent and the reader does not have to think about possible differences in the data caused by different AMF from iDOAS and the satellite.

Ad 2)
In section 3.4 the authors list the main problems in comparing iDOAS data with SCIAMACHY retrievals: the large satellite footprint and the early overpass time more then 2 hours before the flights started. Those two issues could be hugely improved using OMI data instead. OMI overpass time on the 6th of October 2006 is 11:36UT, right at the end of the flight, and OMI8216;s pixels size is significantly smaller than SCHIAMACHY8216;s. I think from an iDOAS versus OMI comparison, the usefulness of iDOAS for satellite validation could be tested much better than it is done in the manuscript so far.

The data are changed to vertical columns throughout the paper.

ACPD

8, S6704–S6711, 2008

A comparison with OMI data for the 6th of October is included, although the resolution of OMI is not much better in this area, as it is covered by the pixels 5 and 6 which are close to edge of the OMI's swath. Since the situation is similar for the other two flights (4 and 5 October) the IDOAS data of this day are compared to both, SCIAMACHY and OMI in section 3.4 "Comparison to satellite data".

Specific comments

-Section 2.1, first paragraph: "..field of view ($5 - 60^o$)..". What does the range 5 to 60^o mean? Isn't the field of view 28^o?

The field of view of the current instrument is 28.8^o but there are other ground based imaging DOAS instrument with different aperture angles. This sentence previously belonged to the previous section were the system is described a bit more in general. Now the correct number is given.

-Fig. 5: I would add "3" in the caption "the total distance between the 3 light sources was 9.9m"; maybe even labelling the light sources in the figure.

Done

- Section 2.2, 1st paragraph: isn't 8 pixels more like 0.9^o?

Yes, it is 0.88^o, we corrected that in the revised manuscript, for the calculation the correct number has been used before.

- Section 2.2, 2nd and 3rd paragraphs: it says the "typical resolution" along track ranges from 90-200m and the "typical integration time" is 1 second or less. I recommend a bit more details for this part: How was the integration time determined? How do (mathematically) the integration time and the flight altitude translate into the along track range?

Let v be the velocity of the plane, and t is the integration time, if α is the aperture angle in forward and backward direction, then the length l of the pixel at the ground is given by:

ACPD

8, S6704–S6711, 2008

$l_{pixel} = v \cdot t + 2h \cdot \tan(\frac{\alpha}{2})$
for a give flight altitude h above ground level.
While the gaps between the pixel are:

$l_{gap} = v \cdot 0.4s - 2h \cdot \tan(\frac{\alpha}{2})$
Both equations are added to the manuscript in section 2.2 equation 2 and 3.

- Section 2.3, last paragraph: I am a bit puzzled, that the AMF is 2.2 for all conditions. Did e.g. the SZA hardly change during the flights? I suggest a bit more explanation in that part.
The referee is absolutely right, assuming a constant AMF without further explanation is not correct. What we intended to say was: the AMF is constant with respect to the viewing angle (typical AMF is 1.8), however it varies with the SZA, as illustrated in Figure 8 of the revised manuscript. We included an aerosol profile in the calculation and assumed a constant mixing ratio up to 2000m AGL and got an AMF of about 1.8. As long as the plane flies above the mixing layer height the AMF does not change with altitude. If the plane is close to the mixing layer hight the AMF increases to 2.2 and decreases to 1.6 when flying only 600 m above ground.
Especially close to power plants - the most interesting use of the Imaging DOAS - the assumption of a constant NO_2 profile is definitely not correct. Therefore a plume of 400m thickness (1900-2300 = 400-800 AGL) is considered, although the air mass factor does hardly change $(\Delta AMF < 0.1)$.
The SZA changes between 21^o and 41^o in this range the AMF for 6300 AMSL flight altitude changes from 1.7 (21^o21 SZA) to 1.9 (40^o21 SZA).
The respective section in the manuscript is changed, including some more details on the AMFs and a new Figure (8).

- Fig. 8: I suggest either using the same color code for both figures or mentioning in the caption the different color coding scales.
Done, the same colour code is used in both figures.

ACPD
8, S6704–S6711, 2008

- Section 2.3, 3rd paragraph: '..(tVCD) is often a more accurate quantity ..” I do not think the word ”accurate” is appropriate in this case. I suggest removing this part and simply combining the two sentences: ”The tropospheric vertical column density (tVCD) gives the integrated ..independent of the light path”.
Done

- Section 3.1, first paragraph: in ”Here only the nadir direction..” Does ”here” refer to figures 8 and 14? Does it mean that the thickness of the lines corresponds to the total swath, but the color is just determined by the nadir pixel?
"Here" refers to figure 8 only, in Figure 14 the average column density is shown. The thickness of the lines does not correspond to the width of the swath, they are given by the minimum size of the dots, in the plotting program, which is necessary to resolve the different in the colours by eye.

- Section 3.3, last paragraph: ”The exact direction .. cannot be determined.” To what level can it be determined?
When the plane was on the ground we put three LEDs underneath, the central one was put in the plumb line under the instrument, the other two were shifted two the right and the left side. The central one was observed in the centre of the CCD, and the other two were imaged on the edges of the CCD. The distance between to central LED was measured to determine the field of view of the installed instrument and to approximate the viewing angle with respect to the plane. But as the distance of the instrument to the ground is about 60 cm a slight error in the position of the LEDs results in a large error in the position of the observed plumes. Approximately the error of the viewing direction is about 3^o if the roll angle was known. As the roll angle of the plane was not measured this also adds to the uncertainty. Overall the uncertainty is about 5^o.
The better way to determine the instruments field of view is to compare the observed patterns in the reflected intensity with high resolution satellite images. The technique is described a bit more in detail now at the end of section 2.2. (see also comment to Reviewer 1)

ACPD

8, S6704–S6711, 2008

- Section 4, 5th paragraph: Maybe the authors could add a few more sentences about the capabilities of the system for measurements other than NO_2 slant columns. Can vertical profiles be measured using varying flight altitudes? What about other trace gases like HCHO? On page 5 it says that CCD lines are co-added to improve the S/N. How many lines would have to be co-added to get sufficient S/N for HCHO retrievals?

The capability of measuring other trace gases than NO_2 mainly depends on the wavelength range during the observation. Thus in principle all the trace gases measurable by DOAS at $\lambda > 300nm$ can be observed e.g. NO_3, $Glyoxal$, $HONO$, BrO, $HCHO$, CS_2

For the data presented here the grating of the spectrometer was turned to the visible range, (370nm-528nm) as no filter was installed the signal was dominated by the range above 440nm. Unfortunately there is a slight misalignment reducing the spectral resolution. Therefore the range between 467 and 517 nm was used for the analysis. Besides NO_2, O_4 and water vapour show some absorption features here, but no significant changes in these two gases were observed. All attempts to find glyoxal (around 460 nm) failed. Probably because the signal to noise ratio was still insufficient. To add several lines on the CCD is not helpful if the calibration or the spectral resolution between the lines changes.

Two further campaigns were performed in the Highveld, and in 2008 the instrument was used in the UV range, here also SO_2 and $HCHO$ were observed, For the SO_2 4 lines were co-added and for the $HCHO$ retrieval it was necessary to co-add at least 8 lines. A respective sentence was included in the conlusion as an outlook on ongoing research.

In future experiment the light throughput might be further improved and thereby the signal to noise ratio will increase as well. This might enable us to retrieve additional species.

To retrieve profile information by changing the altitude might be possible, although we did not try yet. But the change in the AMFs (sensitivity) for a Nadir looking instrument is rather small (see above). If the viewing angle is close to the horizon this approach

ACPD

8, S6704–S6711, 2008

Interactive Comment

seems more promising. The other more elegant way is to observe scattered light from different elevation angles, and to invert the data.

Technical corrections

- Section 1 and fig. 1: in the body text the location is spelled ”Highveld”, in the figure caption it is spelled ”Heighveld”.
The correct spelling is Highveld without an "e".

- Section 1, last sentence: add a dot at the end.
Done

- Section 2, first paragraph: replace ”interesting object” by ”object of interest”.
Done

- Section 2, 2nd paragraph: I suggest removing the last sentence ”They can be colour coded ..”. This is obvious
Done

- Section 2.1, 5th paragraph: The sentence ”As the entrance slit is .. altitude above the ground.” I think this sentence reads better like: ”As the entrance slit is .. total field of view is 28deg and therefore the total swath width at the ground equals half the flight altitude.”
Done

- Section 2.2, 3rd paragraph: AMSL is not defined.
AMSL stands for Above Mean Sea Level, a definition is included.

- Fig. 12, caption: replace”line” by ”lines”.
Done

- Section 4, 1st paragraph: replace ”noe” by ”one”.
Done

- Section 4, 2nd paragraph: replace ”distant” by ”distance”

ACPD
8, S6704–S6711, 2008

Done

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8, S6704–S6711, 2008

Interactive Comment