

## Author's reply to referee #2:

The authors thank anonymous referee #2 for his/her efforts in reviewing our manuscript, which clearly improves during the review process. In the following, the reviewer's comments are printed in black, our replies are indicated in blue. Please find both the reviewer's comments and our point-by-point replies below.

This manuscript introduces a newly developed imaging-DOAS instrument (IMPACT) with the ability to simultaneously measure 50 elevation angles and achieve a panoramic view of the surrounding NO<sub>2</sub> distribution within 15 minutes. This enables the retrieval of tropospheric trace gas profiles at high temporal resolution. The observations presented in this paper were made at Cabauw during the CINDI-2 intercomparison campaign and hence, observations made with IMPACT could be compared with coinciding MAXDOAS measurements. The azimuthal distribution of NO<sub>2</sub> around the measurement site was found to be homogeneous on longer time scales but highly variable on short time scales which is certainly of relevance and interest for the validation of tropospheric NO<sub>2</sub> from satellites. The authors found that one reason for the observed NO<sub>2</sub> variability are transport events and one such event is further investigated in the manuscript. In addition to the NO<sub>2</sub> observations, the potential of O<sub>4</sub> measurements along multiple almucantar scans to be used to retrieve information about the aerosol phase function is investigated as well.

The research described in the manuscript is clearly presented and the manuscript is well written. The scientific content is certainly also relevant for AMT and the paper is recommended for publication in AMT.

Specific comments:

Page 2, line 10-11: Sounds a little strange and since the traffic fleet applies to both, domestic and industrial, I would recommend to delete 'in industry,'. And savanna and forest fires can certainly also be anthropogenic (intentional burn-offs), so needs some rewording.

**The reviewer is correct, we rephrased this sentence to: "Emission sources of NO<sub>x</sub> are both, anthropogenic and biogenic, and comprise e.g. the combustion of fossil fuels for domestic heating and cooking, power generation, traffic, as well as savanna and forest fires."**

Page 2, line 13: Add comma: 'Overall, the ..'

**Included.**

Page 3, line 7: 'In summary, all previously reported ...'

**Changed.**

Page 3, line 14: '...retrieval of the entire ...'

**Changed.**

Page 3, line 15: 'The short acquisition time ...' – although discussed later, it would be good to add already here how long (15 min).

**We added this value here.**

Page 3, line 26: Better: '... be observed by investigating the temporal ...'

**The reviewer is right, we changed that accordingly.**

Page 4, line 12: Better: 'The latter part is ...'

**True, we changed that accordingly.**

Page 4, line 25-27: Sentence could be a bit improved, e.g.: ... either measured at a small solar zenith angle (SZA), or taken ... (sequential), as for the zenith viewing geometry the light path ... is then short'  
**We rephrased the text according to the reviewer's suggestion.**

Page 4, line 28: Add comma after (lo)  
**Included.**

Page 6, lines 1-5: If there are 69 fibres of which are only 50 used, wouldn't the others be a source of straylight in the spectrograph? If so, how is this dealt with?

**This is a very good point! The reviewer is correct, the unused upper- and lowermost individual fibres, which are not mapped onto the CCD (due to its dimension and the magnification characteristics of the spectrometer), do not increase the used signal, but certainly increase straylight inside the spectrometer and therefore decrease the ratio  $I_{\text{used}}/I_{\text{straylight}}$ .**

**In general, straylight is accounted for in the DOAS analysis by means of an intensity offset correction (usually applied in DOAS fits). The straylight corrections was of zeroth order, which was prescribed by CINDI-2 fit settings (see Tab. 1, which is Tab. 2 in the revised manuscript after suggestions from referee #1). However, in future applications, light from unused fibres should be blocked (respective fibres should be blocked at the entrance slit) to reduce potential straylight problems.**

**We addressed this issue by including the intensity offset correction explicitly in the description of the DOAS analysis (Sect. 2.1). In addition, we rephrased the respective paragraph: "However, as a result of the size of the CCD and the magnification characteristics of the spectrometer, light from the upper- and lowermost fibres do not hit the detector (these fibres are imaged outside the detector area), so that only 50 individual fibres are fully mapped on the CCD used here. This is a non-optimal setup as these fibres do not contribute to the used signal, but enhance straylight within the spectrometer. Although straylight effects are compensated by the intensity offset correction in the later DOAS fit (see Sect. 2.1), light from this non-contributing fibres should be blocked in future applications to reduce potential problems with straylight."**

Page 6, lines 18-19: Add commas after 'instrument' and after '(Sect. 2.4)'  
**Included, thanks.**

Page 10, lines 8-9: replace 'realize' with either 'note' or 'acknowledge' and add 'the' before 'telescope elevation'  
**The sentence was rephrased accordingly.**

Page 10, line 11: Delete 'promptly'  
**Removed.**

Page 12, line 21: 'molec cm<sup>-2</sup>' needs -2 in superscript  
Caption of Figure 7: Any reason why that particular period (17-23 Sep) was picked and not e.g. the complete campaign period?

**Thanks, we corrected the superscript. The reason for the limited period in Fig. 7 is data availability. Unfortunately, not the entire intercomparison period could be covered. IMPACT operated from Sep. 16 in the afternoon until Sep. 24 in the morning when a breakdown occurred. Complete days of parallel operation of MAX-DOAS and IMPACT are therefore 17 – 23 September, which is the time period shown here.**

Page 14, line 13: Replace 'persistence' with 'persisting', right?  
**Yes, many thanks. We corrected this.**

Page 14, line 15: Should be 'overall'  
**No, but the "average of all" (instead of "mean over all") is meant. We corrected this.**

Page 14, line 24 etc.: Would be interesting to know how many such transport events could be identified within the campaign period. Could you add that to the discussion?

This is a good question which is not easy to answer as we did a qualitative analysis of a specific (the largest occurring) transport event, instead of a quantitative retrieval of the number of transport events. Thus, we cannot give a certain number as we did not elaborate a detection algorithm. However, some events like the analyzed one on 20 September are easy to find manually e.g. from Fig. 9 in the manuscript (which is Fig. 1a below) as hints for a transport event are 1) peaks in the (mean)  $\text{NO}_2$  slant columns and 2) peaks in the azimuthal variations of  $\text{NO}_2$  meaning that some azimuthal directions are enhanced while others are not. The event on 20 September is by far the strongest observed variation and explains the largest maximum relative differences (Fig. 1b) during the whole campaign. However, on other days like September 19 (Fig. 2a below), 2 other transport events likely occurred around 9:00 UT and 12:00 UT, while for example on September 18 (Fig. 3a below), no transport event at all is seen. However, the  $4^\circ$  elevation is shown here (arbitrarily) and transport events passing the instrument in a closer distance would enhance predominantly measurements at larger elevations and are thus most likely missed. Therefore, a much more comprehensive analysis is required for a quantitative analysis. In addition, enhancements of the light path due to clouds or aerosols would also enhance the  $\text{NO}_2$  and thus could be misinterpreted as  $\text{NO}_2$  transport event.

In conclusion, a detection algorithm for transport events was not elaborated and is difficult to implement. Nevertheless, the reviewer's suggestion is very good as a quantitative analysis retrieving the number of transport events is valuable information for satellite validation activities. We therefore suggest including this activity in the next  $\text{NO}_2$  intercomparison campaign.

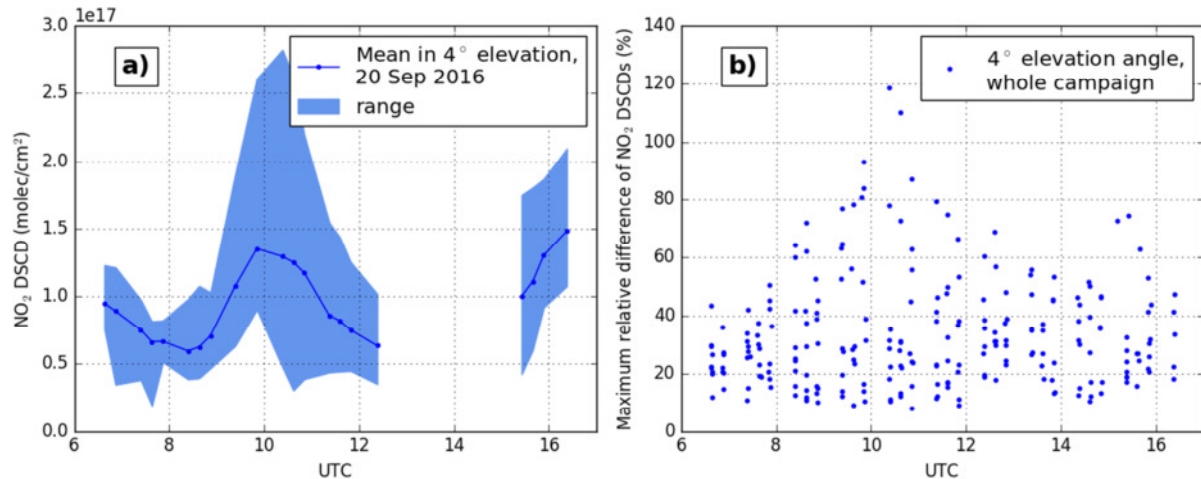


Fig. 1: Original figure from the manuscript (transport event on September 20 in subplot a)

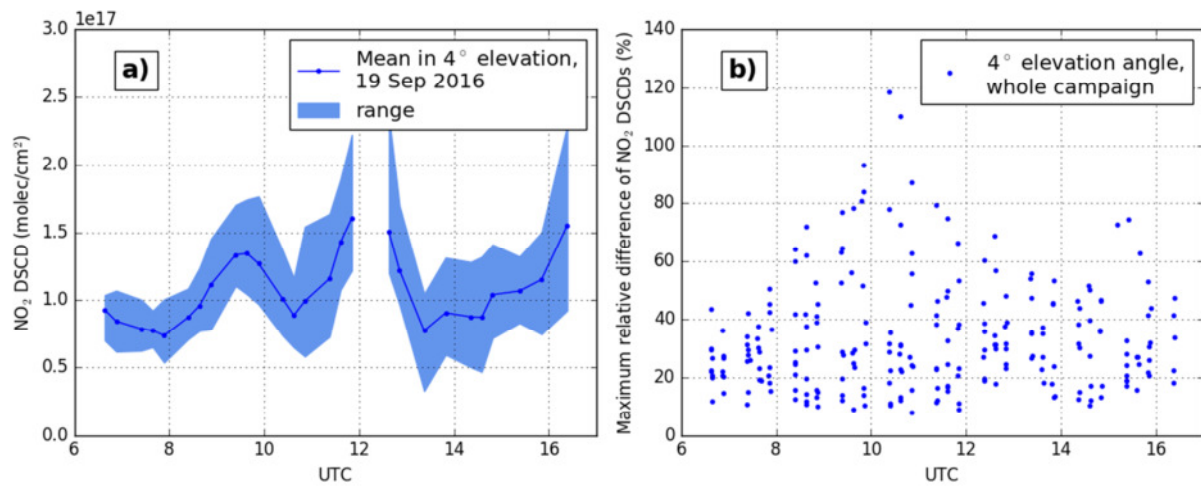


Fig. 2: The same figure, but subplot a) is replaced by September 19.

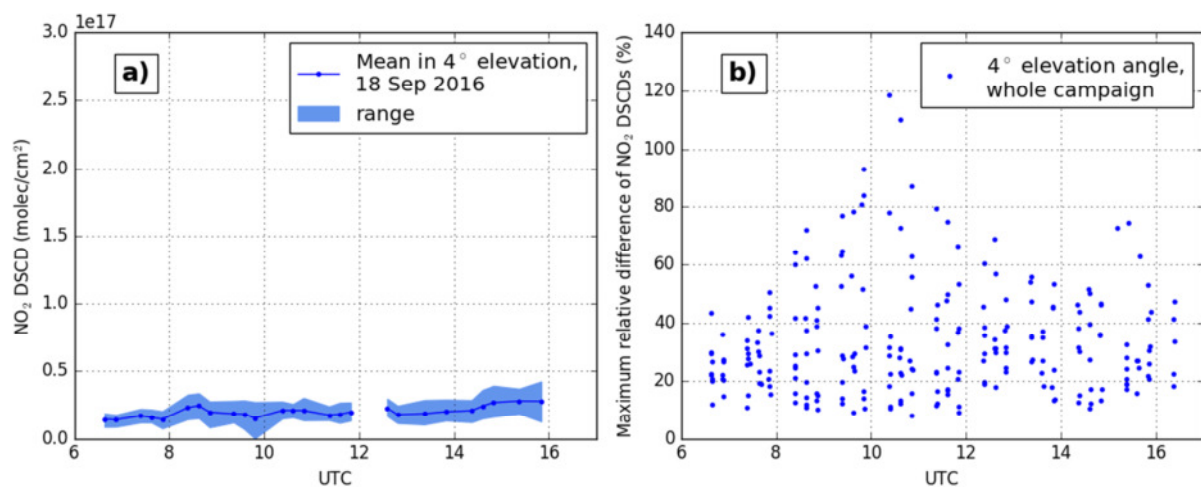


Fig. 3: The same figure, but subplot a) is replaced by September 18.

Page 15, Figure 8 caption: Could you please add here the time period used (i.e. averaged over)? I assume it is the complete campaign period?

**This is the mean of all available IMPACT panoramic images. Due to instrument problems (as mentioned above) this is unfortunately not the complete semi-blind intercomparison period, but limited to the period from September 16 (afternoon) to September 24 (morning). We added the time period in the revised manuscript.**

Page 17, Figure 12: Would be helpful if the blue arrow head could be bigger; in my printout, it was not really detectable.

**Thanks for this hint, we increased the arrow head.**

Page 20, line 17: Add comma after 'question (1)'

**Included, thanks.**

Page 23, line 4: Add 'with' after 'interfering'

**Added.**