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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Highly resolved global distribution of tropospheric NO_2 using GOME narrow swath mode data" *by* S. Beirle et al.

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First we would like to thank the reviewers for their constructive comments and questions, helping us to identify unclear passages in our manuscript and improving readability, clarity and the direction of our study. Furthermore, we thankfully adopted several specific suggestions for reformulations. We followed the reviewers' suggestion to let a native speaker cross-check our manuscript, improving style and grammar.

In this general reply, we refer to the major aspects addressed by the reviewers. Specific comments and questions are handled in the individual answers.

Especially Rev#2 asked for the scientific relevance and the new results of our study. We therefore emphasize the main results, new methods, and scientific benefits, in our manuscript.

We wish to stress the following aspects:

1. We retrieved a map of tropospheric NO2 VCD in unprecedented resolution.

2. To this end, we developed a new method for a deseasonalization procedure using the NSM backscan.

3. We could estimate an upper limit for the mean lifetime of tropospheric NO2 on a global scale.

4. We could identify the main limitations of the common GOME resolution by comparing the NSM and SSM results quantitatively.

5. We analyzed the dependency of cloud fraction on pixel size and its influence on the comparison of NSM/SSM NO2 VCDs.

ad 1. We used the NSM GOME observations to retrieve the global distribution of tropospheric NO2. The resulting map already is a valuable result, since it shows the location of NOx sources on a global scale with unprecedented spatial resolution. We find characteristic patterns that allow us to identify particular sources like the Four Corners power plant in the USA. Our data product helps to validate emission inventories. For instance, we detect sources that are clearly underestimated in the EDGAR inventory (e.g. Piedras Negras, marked grey in Fig. 5a).

ad 2. To retrieve the global map in this quality, we had to deseasonalize the (sparse) data. Instead of filtering (which would reduce the spatial resolution) we compared the NSM backscan to the mean of SSM forescans. As far as we know, this method is new and proved to be quite successful.

ad 3. The small extent of the NO2 "hotspots" defines an upper bound for the mean lifetime tau of tropospheric NO2 of 17 hours, even for northern locations like Moscow. Since tau is highly variable in space and time, and current knowledge is restricted to (sparse) local measurements and models, our upper limit estimate on a global scale provides important supplementary information.

ad 4. A quantitative comparison of NSM and SSM forescan (or NSM backscan, re-

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spectively), holds information on the influence of the pixel size on the retrieved results. This is valuable additional information for the interpretation of the common GOME SSM results, and will probably prove also to be relevant if GOME data is compared to results of SCIAMACHY or OMI (e.g. in future trend studies). The difference map in Fig. 7 also allows to identify local hot spots in polluted regions (like Torino).

We compare the maxima in the SSM and the NSM over source regions. The ratio of both holds information on the spatial extent of the source. High ratios allow deduction of plume dimensions that lie below the NSM resolution.

ad 5. The comparison of cloud fraction distribution for NSM and SSM pixels holds information on typical spatial scales of clouds. NSM pixels are more often cloud free than SSM pixels, and for heterogeneously clouded scenes, backscan observations result in lower VCDs than the averaged forescan pixels, since the clouded fraction of the pixel is brighter. Though we find a nearly 1:1 relation of the NSM backscan via the mean of the respective forescans (Fig. 9). This turned out to be not as surprising as we stated in the ACPD manuscript, since a) those events, where a totally clouded pixel lies next to a totally cloud free pixel, are extremely rare and b) the actual intensities of the light reflected by clouds are only higher by a factor of about 5 instead of 16 (as assumed in the previous version of Fig. 8) as a consequence of Rayleigh scattering in the considered wavelength range (430-450 nm). We modelled the expected underestimation of the backscan observations as illustrated in Fig. 8 by scanning a constant tropospheric VCD with different cloudy scenarios (taking from the actual GOME measurements), and found it to be only 2% (NSM) and 4% (SSM), respectively.

We therefore largely revised paragraph 5. To exclude possible interference with snow cover, as remarked by Rev#1, we confine our analysis to summertime observations in the polluted northern hemisphere. The 1:1 relation of Fig. 9 remains unaffected. We revised Fig. 8 and added the effect of Rayleigh scattering. Furthermore, we added a plate to Fig. 9 showing the SSM observations. The effect is quite similar there. We illustrate our main findings in an additional Figure (10), showing the ratio of maximum and minimum intensity within the six forescans covered by one backscan pixel, as a dependency of the difference in cloud fraction. This figure shows that - large differences in cloud fraction are very rare and - the maximum intensity exceeds the minimum by a factor of 6 in extreme cases, but only by 1.8 on average.

The NSM-SSM comparison of cloud fraction reveals new insights in the spatial patterns of cloud coverage and their general impact on tropospheric column retrieval. However, in the context of our study we concentrate on the equality of mean NSM forescan and NSM backscan VCDs. We could show, that the systematic underestimation of backscan observations is so marginal that it is not contradictory to Fig. 9. So we can conclude that clouds, though shielding the boundary layer and resulting in generally underestimated column densities, do not undermine our results, i.e. the retrieved map of trop. NO_2 of high spatial resolution.

A systematic analysis of the dependency of VCD on cloud fraction (for different regions) is in progress, but goes beyond the scope of the manuscript presented here.

In our revised manuscript, we sharpened our scientific work as well as our major results and their importance. Major revisions beyond the items above are enumerated below:

- we extended the paragraph on the retrieval of tropospheric NO_2, adding a description of our stratospheric estimation, our AMF correction and the general role of clouds.

- we extended the discussion of our lifetime estimate and relate it to model and measurement data.

- we revised Fig. 6: In the context of our deseasonalization algorithm, we compare the NSM backscan with the SSM forwardscans. While their spatial extent is similar, it is not exactly the same. As the NSM backscan is smaller than the SSM (i.e. the NSM backscan results in a higher VCD than the forescan mean and thus our seasonal bias estimation is too high), we tend to underestimate the NSM peak VCDs over remote hotspots. We account for this effect in connection with the discussion on the smoothing

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effect illustrated in Fig. 6 by also applying the "seasonal correction" there. This modifies the ratios of the simulated NSM and SSM maximum. Furthermore, we changed the FWHM in Fig. 6a/b to 30 and 60 km, respectively, since the latter results in a ratio of 3.17 that is close to the measured value for Mexico city.

Interactive comment on Atmos. Chem. Phys. Discuss., 4, 1665, 2004.