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Interactive comment on "An improved tropospheric NO_2 column retrieval algorithm for the Ozone Monitoring Instrument" *by* K. F. Boersma et al.

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We thank Ref#1 for his or her constructive comments and suggestions. Below we address these one by one.

What is the overall error in the v2.0 algorithm? How does that error compare to the error estimate in the v1 algorithm?

In our v2.0 algorithm, a number of systematic retrievals errors is addressed, which improves -in theory- the accuracy of the NO_2 retrieval by the numbers stated in Tables 2 and 3. In different words, our previous v1.02 retrieval was likely biased high by 0-40%, and our improved v2.0 algorithm reduces the (bias in) v1.02 columns by 10-20%.

The uncertainty (defined as the random error for an individual retrieval) of v2.0 has not improved much relative to v1.02. This uncertainty is primarily determined by the errors in the air mass factor dependencies and these vary in space (from one pixel to the other) as well as in time (from one day to the other). By improving the spatial resolution and quality of the surface pressure and surface albedo data, the contribution of these parameters to the overall uncertainty has definitely decreased, but the errors from cloud parameters and a priori profile shapes propagate unabated. Based on our earlier error propagation studies, we cautiously estimate that the stated uncertainty of $\sim$30% for v1.02 [Boersma et al., 2007] improves to $\sim$25% for v2.0.

We added the following text to section 5: "The uncertainty in DOMINO v2.0 tropospheric NO_2 columns has probably decreased relative to v1.02. The improved spatial resolution and quality of the surface pressure and surface albedo data are likely to decrease the contribution of these parameters to the overall uncertainty. Because the errors from cloud parameters and a priori profile shapes propagate unabated, we cautiously estimate that the stated uncertainty of $\sim$30% for v1.02 [Boersma et al., 2007] improves to $\sim$25% for v2.0."

What are your remaining concerns with the v2 algorithm? A paragraph would be helpful.

We added at the end of section 7: "Tropospheric NO_2 retrievals for existing platforms can be further improved by better knowledge of the state of the atmosphere for individual pixels. The largest gains will likely be obtained by higher-resolution a priori profile shapes, and improved surface albedo databases. For the DOMINO v2 algorithm, an improved description of stratospheric chemistry in TM5 [Dirksen et al., 2011] is expected to improve our data assimilation for situations when the denoxified air masses make excursions into polluted continental regions. We anticipate that the next major update (v3) will consist of coupling our retrieval to TM5 (with 1° x 1° instead of 3° x 2°)

capability and improved stratospheric chemistry."

The aerosol study is valuable to assess the implicit behaviour of the OMI cloud correction algorithm. However, the implicit mean aerosol pressure over the eastern US of 720 hPa (p2353) is concerning. This implies that half of the optical effect from aerosols is at pressures lower than 720 hPa. The cited references do not support so much aerosol aloft over the southeast US: Turner et al. (2001) is for the Great Plains and Liu et al. (2008) focuses on mineral dust. The aerosol profiles in Lewis et al. (2010) show most of the aerosol in the PBL. More evidence is needed to demonstrate that such a low pressure (high altitude) is appropriate. For example, what does Calipso show over the Southeast US? Or INTEX-B? Figure 1 of Jennifer Hains' thesis is another good resource. I'm concerned that this low pressure implies an error in the ability of the cloud correction to properly treat aerosol.

We thank the reviewer for raising this point. As recommended, we reviewed the literature on the vertical distribution of aerosols over the eastern US. We have replaced the Liu et al. (2008) reference by the more appropriate Yu et al. (2010) citation that reports on observed CALIPSO aerosol profiles over the eastern US. The CALIPSO measurements for summer 2007 in Yu et al. (2010) generally support significant aerosol aloft, peaking at ~2 km, but also with considerable aerosol extinction up to 5 km. We would still like to cite the Turner et al. (2001) paper since we focus on elevated aerosols over the eastern US, and the Oklahoma site reported in Turner et al. (2001) falls well within the domain shown in Figure 11. Nevertheless, our retrieved OMI O_2-O_2 cloud levels are still above the reported aerosol levels, so we evaluated the O_2-O_2 algorithm once more and found indications for our cloud pressures to be on the low side.

The O_2-O_2 cloud pressure has a temperature dependence, which has not yet been taken into account in the operational retrieval. This dependence is due to the quadratic dependence of the O_2-O_2 number density. The retrieval uses the mid latitude summer standard atmospheric temperature profile for all scenes, which may be different from the actual temperature profile. A higher temperature leads to a lower number density of

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O_2-O_2 collision complexes, and thereby to lower retrieved cloud pressures. Simulations suggest that the bias in cloud pressure is <50 hPa for a surface temperature increase of 20K relative to the MLS temperature for effective cloud fractions > 0.2. However, for cloud fractions < 0.2, the retrieved cloud pressures may be too low by up to 50-200 hPa. We therefore estimate that for a temperature increase of 10 K, which may be expected in this season over the eastern US, the retrieved cloud pressures are too low by 25-100 hPa.

We have updated Section 6 accordingly: "For high AOT (increased effective cloud fractions) in the southeastern United States, O_2-O_2 pressures are lowest, indicative of elevated aerosol layers. The median O_2-O_2 pressure corresponds to 720 hPa for hazy situations with MODIS AOT >0.2. These elevations are somewhat higher than the significant amounts of aerosols well above the boundary layer in the summertime (south)eastern United States as observed with ground-based, airborne, and space-based lidars [Turner et al., 2001; Lewis et al., 2010; Yu et al., 2010]. Because of differences between the mid latitude standard atmosphere temperature profile used in the O_2-O_2 retrieval and the actual, higher temperatures over the eastern United States in July 2005, it is likely that the number density of the O_2-O_2 collision complexes is underestimated, leading to lower cloud pressures. Additional simulations suggest that the bias in cloud pressure is <50 hPa for a surface temperature increase of 20 K relative to the mid latitude standard temperature for effective cloud fractions >0.2. However, for cloud fractions <0.2, the retrieved cloud pressures may be too low by up to 50-200 hPa. We therefore estimate that for a temperature increase of 10 K, which may be expected in this season over the eastern United States, the retrieved cloud pressures are too low by 25-100 hPa. Bearing these biases in mind, we examine the vertical differences between the cloud pressures and the a priori NO_2 profile, by comparing the probability distribution of cloud pressures to the average NO2 vertical distribution simulated by TM4 under 'hazy' conditions (AOT >0.2)."

Also, in the remainder of Section 6, we have changed the wording to reflect that we

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now have a better understanding of the discrepancy between the aerosol corrections based on radiative transfer simulations and based on the implicit cloud corrections.

Why does the v2 algorithm use an OMI surface reflectance from only three years of observations? Wouldn't a longer record lead to a better product?

We use the OMI surface reflectance that was available when we started this work. This OMI surface albedo dataset has been peer-reviewed (Kleipool et al., JGR, 2008), and tested in our retrievals (Hains et al., JGR, 2010). Given OMI's extensive coverage, the statistics for the Kleipool et al. (2008) dataset are comparable or better than the 5.5-years GOME or 13-year TOMS-based albedo datasets. In the future, we will use a new version of the OMI surface albedo (based on 4 years of data) that has become available in the meantime.

Line 22 of p2349 comments that the effect of destriping has not been investigated for dates later than June 2007 when fewer rows are available for averaging. Please do check this effect.

Ref#2 also asked a question about the performance of de-striping for later years and we have now replaced Figure 8 by a new one that includes the corrections for the 1st of January for 2005 up to 2009 (we haven't reprocessed later years yet). We updated the text as follows: "Our correction method discards rows (from the boxcar averaging) that have been affected by row anomalies occurring along the complete orbit, but works the same otherwise. From the corrections we obtain for 1 January 2008 (when row 53 was discarded) and 1 January 2009 (when rows 38-43 and 53 were discarded), we see that the method still results in similar but somewhat stronger corrections for the later years. The root mean square correction (per row) has increased from 3.6×10^{14} for 1 January 2005 to 5.3×10^{14} molec.cm^{-2} for 1 January 2009, reflecting the degradation in OMI and the fact that the 2005 average irradiance measurements are less appropriate as reference spectra for later years. Nevertheless, the monthly mean tropospheric NO_2 column fields shown on www.temis.nl suggest that the destriping remains effective, also for later years.

Figure 13 would be clearer if the TM4 partial column were plotted in mixing ratio. The partial column depends on the vertical grid.

Agreed. We now present TM4 mixing ratios in Fig.13.

Specific P2344, how does the algorithm perform over snow and ice in winter.

Because the O_2-O_2 cloud retrieval has difficulty in distinguishing bright snow and ice from clouds, our cloud fraction and cloud pressure are unreliable over snow and ice. We therefore flag our retrievals in such situations. Because the slant columns and stratospheric slant columns are in principle well-retrieved over bright scenes, we feel that a dedicated study into the quality of the air mass factor may help in establishing the quality of the tropospheric columns under these circumstances. Such a study has not yet been carried out for the DOMINO retrievals.

L22, p2340, "to for"

Corrected.

L4, p2359, recommend changing "has become" to "is treated as being"

Done.

L5, p2359, recommend adding "is treated as" prior to residing

Done.

P2348, principle.

Corrected.

Interactive comment on Atmos. Meas. Tech. Discuss., 4, 2329, 2011.