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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Three years of greenhouse gascolumn-averaged dry air mole fractionsretrieved from satellite – Part 1:Carbon dioxide" *by* O. Schneising et al.

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Author's answers to interactive comments of S. Houweling on paper Schneising et al., Atmos. Chem. Phys. Discuss., 8, 5477–5536, 2008

First of all we would like to thank S. Houweling (in the following referred to as the referee) for his very critical but constructive comments. Below we give answers to all these comments which will all be considered for the revised version of the manuscript.

The referee is not convinced that the elevated CO_2 retrieved over Europe's highly populated areas of The Netherlands/Belgium/Western Germany (roughly located be-

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tween Amsterdam and Frankfurt and referred to as Rhine-Main area in the following) is due to anthropogenic CO_2 emissions. He argues that it is rather straight forward to estimate the impact of the anthropogenic emissions on the total column. To estimate this he and his colleagues used CarbonTracker at 1x1 degree resolution over Europe and sampled the model at SCIAMACHY overpass times. From this he concluded that the model could support an anthropogenic signal in the Rhine-Main area of 1 ppm at most.

As described in our paper we apply a quite strict quality filtering to our data. Because of this only about 60 SCIAMACHY measurements are averaged per 0.5x0.5 gridcell in the Rhine-Main area shown in Fig. 16 of our paper (over large parts of the Netherlands the number of measurements per 0.5x0.5 gridcell is even less, about 20). As a consequence our average of three years of SCIAMACHY data over central Europe is not the "true" average but an average significantly influenced by the (sparse and irregular) sampling of the satellite data which are weighted towards (nearly) cloud free scenes during spring, summer and autumn. This sparse sampling was not considered in the estimate computed by Houweling. In Palmer et al., 2008, maps of the contribution of North American anthropogenic CO_2 emissions to monthly mean CO_2 column-averaged mixing ratios are shown derived using the GEOS-Chem model (their Fig. 7, left hand side panels) for April-September 2003. The model has been sampled as SCIAMACHY (using a filtering of the SCIAMACHY retrievals as implemented in the FSI-WFM-DOAS algorithm which is (although similar) independent of the algorithm and results shown in our paper). In that paper it is shown that especially over the highly populated areas along the US eastcoast the anthropogenic CO_2 enhancement often exceeds 1 ppm and reaches for several months 2 ppm although the model resolution is only 2x2.5 degrees. Although for a number of reasons differences can be expected between the highly populated areas of US and Europe we are therefore not entirely convinced that 1 ppm is really the upper limit. In the future we will aim at using model data with high spatial resolution to better estimate the anthropogenic signal by

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taking the exact sampling of our satellite retrievals into account. For now we assume that the 1 ppm estimate derived by the referee is at least a reasonable estimate.

Because of the sparse sampling the regionally elevated CO_2 as obtained from SCIAMACHY and shown in Fig. 16 of our paper is influenced by sampling. On average, the largest atmospheric CO_2 variation is caused by uptake and release of CO_2 by the biosphere which results in a strong seasonal cycle with an amplitude of several ppm. If for example the sampling rate over the Rhine-Main area around April, where the northern hemispheric CO_2 is highest, is larger compared to the surrounding areas (e.g., due to more cloudfree scenes over Rhine-Main) the result will be elevated CO_2 over the Rhine-Main area not caused by local emissions but by the irregular sampling. To investigate if and how the results shown in Fig. 16 are affected by sampling we aimed at filtering out the seasonal (biospheric) variations. We used two approaches: (i) We averaged the (daily) ratio of the retrieved XCO_2 with the CarbonTracker XCO_2 (this assumes that CarbonTracker captures the seasonaly cycle well but does not resolve the spatial features under consideration), and (ii) we averaged daily anomalies, i.e., we computed for each day the average XCO_2 over the scene shown in Fig. 16, and subtracted this average from the daily data before averaging the daily maps over the three years. We will discuss the results of this study in detail in the revised version of the paper. Here a short summary of the main results. We found that even if the seasonal cycle is filtered out there is still clearly elevated CO_2 over the Rhine-Main area. Depending on which of the two methods is used the spatial pattern of the CO_2 are somewhat diffent but only slightly. Here some numbers to quantify this based on defining two (rectangular) regions, one corresponding to the Rhine-Main area and one background (reference) region located eastward. The CO_2 enhancement over the Rhine-Main area is 2.7 ppm (compared to the reference region) when the data shown in Fig. 16 are averaged. When the seasonal cycle is filtered out the CO_2 is elevated by 2.6 ppm when using the daily mean anomaly method and by 3.3 ppm when using the ratio with CarbonTracker. From this we conclude that the sparse and irregular

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sampling cannot explain the elevated CO_2 over the Rhine-Main area shown in Fig. 16.

In this context we also looked at yearly averages. Elevated CO_2 over Rhine-Main is also observed when only averaging year 2003 data (enhancement: 1.9 ppm), year 2004 data (0.6 ppm) and 2005 data (4.6 ppm). These results show that the CO_2 is persistently elevated during all three years but also that the year-to-year variations of the retrieved enhancements are quite large. This is very likely a combined effect of the relatively low precision of the measurements and the sparse sampling. As shown in our paper the single measurement precision is about 1-2% corresponding to about 4-7 ppm. In order to detect a signal on the order of 1 ppm the (single measurement) precision has to be improved by a factor of 7. Assuming that the precision improves with the square root of the number of measurements added this means that more than 50 measurements need to be averaged per 0.5x0.5 degree gridcell before a 1 ppm signal can be detected at 0.5x0.5 degree resolution (assuming a single measurement precision of 7 ppm). For the three years average this is achieved for nearly the entire region shown in Fig. 16 (except for coastal areas including large parts of the Netherlands) but not for one year averages. For the south-western part of the Netherlands, for example, there are nearly no data during 2004 and the elevated CO_2 over the Netherlands is mainly due to 2003 data (slight elevation) and 2005 data (significant elevation). As a consequence we found that the elevated CO_2 over the Netherlands is less stable (e.g. with respect to smaller averaging time periods) compared to the German part of the Rhine-Main area where significantly more data are available. These considerations show that the expected signal (1 ppm) is close to the detection limit of the SCIAMACHY instrument even if three years of data are averaged. Therefore we do not claim in our paper that these measurements are useful for quantifying anthropogenic CO_2 emissions but only refer to the detection of the anthropogenic signal.

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In the revised version of the paper we will modify the sentence with the statement that the retrieved enhancements are “only on the order of 1 percent (4 ppm)” taking into account the comments made by the referee.

We will also change the color scale as suggested by the referee (Fig. 16 EDGAR emissions).

The referee is right that parts of the retrieved elevated CO_2 may be due to interference with aerosols. In the revised version of the paper we will discuss this aspect in more detail. We will present (i) a more detailed error analysis based on simulated retrievals, retrieved albedo variability and independent realistic aerosol information, (ii) a discussion of satellite derived aerosol optical depth over Europe during 2003-2005 (magnitude, spatial pattern), and (iii) an estimate of the aerosol related error based on an analysis of the simultaneously retrieved methane columns (Schneising et al., 2008). From (i) and (ii) we estimate that the aerosol related error is about 0.5 ppm (relative systematic error Rhine-Main versus surroundings) for a three years average. To derive this estimate we had to make assumptions. Therefore one may argue that the real error is larger. To address this we also estimated this error using an alternative approach based on simulated and real SCIAMACHY data. Our error analysis based on simulated measurements shows that the XCO_2 error depends significantly on the aerosol scenario assumed but that this error is very similar for methane retrieved from a nearby spectral fitting window (Schneising et al., 2008). From this one can conclude that if the XCO_2 spatial pattern over Europe is to a large extent due to aersols that a significant correlation with XCH4(O2) should result, where XCH4(O2) is (essentially) the retrieved CH_4 column divided by the retrieved O_2 column (note that the discussed XCO_2 is (essentially) the retrieved CO_2 column divided by the retrieved O_2 column). As will be shown in the revised version of the paper the XCO_2 and XCH4(O2) spatial pattern show some correlation but a clear enhancement of the XCH4(O2) over the

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Rhine-Main area is not observed. Using this alternative approach we estimate that the aerosol related error may explain up to 0.9 ppm of the observed enhancement of 2.7 ppm (which is larger that the 0.5 ppm estimated using the method desribed above but this was to be expected at the method based on the retrieved methane is influcenced by atmospheric methane variability). From this we conclude that aerosols may contribute to the observed enhancement but can only explain a fraction of the observed enhancement.

Overall we conclude that the elevated CO_2 over Rhine-Main, which is about 2.7 ppm on average has an estimated uncertainty of about 1-1.5 ppm due to aerosols and sampling contributions. Taking this into account the signal is still higher than the upper limit of 1 ppm estimated by the referee. The remaining discrepancy is still significant and requires further investigations e.g. by detailed comparisons with high resolution model data sampled taking into account the filtering (sampling) of the satellite retrievals and likely also using more sophisticated methods of quantifying the uncertainty of the satellite XCO_2.

We will mention in the revised version of the paper that the retrieved CO_2 is also elevated over several other anthropogenic source regions such as the east coast of the US, parts of Japan (e.g., around Tokio) and parts of China (around Beijing and over the highly populated area between Nanjing and Shanghai).

Overall we think that we can provided evidence that the elevated CO_2 detected over the Rhine-Main area cannot be fully explained by sampling and aerosol related errors as argued by the referee. According to our studies sampling and aerosols may however explain up to 50% of the excess CO_2 over the Rhine-Main area. Taking into account the (small) magnitude of the expected signal as estimated by the referee (1 ppm) in combination with the difficulty of accurately quantifying the error of the highly

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averaged satellite XCO_2 data we can at this stage strictly speaking not proof that the observed elevated CO_2 is mainly caused by anthropogenic emissions. To consider this we will replace “can be detected” by a less strong statement as also suggested by one of the other two referees.

References:

Palmer et al., 2008, ACPD, 8, 7339-7371.

Schneising et al., 2008, ACPD, 8, 8273-8326.

Interactive comment on Atmos. Chem. Phys. Discuss., 8, 5477, 2008.