Authors' answer to the interactive comments of anonymous referee #1 on paper Heymann et al., Atmos. Meas. Tech. Discuss., 5, 4285-4320, 2012

First of all we would like to thank the referee for the helpful comments and questions. Below we give answers and clarifications to all comments and questions made by the referee.

Referee: *"To my knowledge, the paper under review is the fourth paper in a series of papers which compare the SCIAMACHY WFM-DOAS CO2 product v2.x to TCCON and/or Carbon-Tracker. The other papers are Schneising et al., 2011, Schneising et al., 2012, Heymann et al., 2012. These studies are referenced appropriately by the manuscript. The present manuscript shows that the reanalysis of two postprocessing filters and the addition of a cirrus filter improve the WFM-DOAS CO2 product. This is new insight into the dataset but – in the view of collecting scientific mass - one might wonder if a previous publication such as Heymann et al., 2012, was the more appropriate place to cover it."*

Authors: The SCIAMACHY WFM-DOAS v2.1 XCO_2 data product is the only available SCIAMACHY XCO_2 data set described in the peer-reviewed literature and therefore has a large user community. This community is potentially interested in important scientific topics like the validation of the data set (Schneising et al., 2012), the investigation of the impact of potentially error sources like scattering by aerosols and thin clouds on the data product (Heymann et al., 2012) and the development of a new version of the WFM-DOAS retrieval algorithm which is based on a new cloud filtering and correction method and which was used to generate a strongly improved SCIAMACHY XCO_2 data product (shown in this paper). In our opinion, this is not a collection of scientific mass but rather research and development.

We also discussed combining the publications. However, the topics discussed in Heymann et al. (2012) and in this manuscript are thematically well separable and a combination of the papers would result in an overloaded and too long paper. This is also not possible anymore as Heymann et al. (2012) has already been published.

Referee: *"Why do you use such a wide spectral range for cloud detection (1.395-1.410 micron, while 1.390-1.410 micron in the figures)? There should be wavelength ranges in this band that are entirely opaque for essentially all occurring ambient H2O abundances. This would greatly simplify the empirical definition of a reference intensity."*

Authors: We have used a wide spectral range (15 nm) in order to reduce the statistical error. This was mentioned in the revised version of the paper in the following way: "We use sun-normalised radiance ("intensity") spectrally averaged between 1.395–1.41 μm measured by 20 detector pixels of SCIAMACHY channel 6. We spectrally average the intensity to reduce the measurement error to about 0.1 %."

The used wavelength range is entirely opaque for essentially all occurring ambient H_2O abundances. As can be seen in Fig. 1, the reference intensity is nearly stable for most of the measurements. This has already been discussed in the paper: "As can be seen, the reference intensity is nearly constant if the H_2O^{VCA} is larger than 1 $g\,cm^{-2}$. With decreasing H_2O^{VCA}, the reference intensity increases and its standard deviation as well. However, only a small fraction of the retrieved H_2O^{VCA} is lower than 1 $g\,cm^{-2}$ and the relaxed filtering threshold prevents from flagging too many clear-sky data as cloudy."

Referee: *"If the deviation of the measured intensity [...] to a reference intensity [...] is larger than a factor of 2". I find the wording confusing. The threshold is put at 3-times the reference intensity (figure 3), right? Consider to rephrase."*
Authors: Yes, this is right. The text was improved.

Referee: *"Did the simulations resulting in Figure 3 and Table 1 use Mie scattering properties or cirrus scattering properties? This is important, since previous publications [eg. Schneising et al., 2011] found that cirrus scattering was the most important error contaminating the WFM-DOAS dataset. If cirrus scattering is not considered by the simulations, this has to be reevaluated."*
Authors: We have used cirrus scattering properties. In order to give more specific information about the used simulation scenario, we added the following description: "The scenario of the radiative transfer simulations has been defined as follows: Only direct nadir conditions (viewing zenith angle of 0°) are considered. In order to simulate cirrus clouds, an ice cloud with fractal particles based on a tetrahedron with an edge length of 50 μm, with a cloud top height (CTH) of 10 km and a geometrical thickness of 0.5 km is used. The used aerosol profile (default aerosol profile) is based on a realistic aerosol scenario (see the OPAC background scenario) described by Schneising et al. (2008)."

Referee: *"Table 1 covers too few scenarios too draw conclusions such as discussed in the paragraph beginning with p.4293, l.21. Please extend the parameter range."*
Authors: For the revised version of the manuscript we used an extended parameter range. This parameter range is as follows (the new parameters are shown in bold):

- solar zenith angle: 20°, 40° ,60°
- albedo: 0.1, 0.3, **0.6**
- cloud top height: 4 km, **7 km**, 10 km, **13 km**, 16 km

- water vapour column amount: 0 gcm^{-2}, 0.14 gcm^{-2}, 0.29 gcm^{-2}, **0.57** $\mathbf{gcm^{-2}}$, 0.86 gcm^{-2}, **1.14** $\mathbf{gcm^{-2}}$, 1.43 gcm^{-2}, 2.86 gcm^{-2}, 4.29 gcm^{-2}, **7.15** $\mathbf{gcm^{-2}}$

The discussion starting at page 4293 line 21 was updated according to the results of the new simulation scenarios in the following way: "The saturated water vapour absorption band based cloud filter is sensitive to thin (COD > 0.05) and high (CTH > 4 km) clouds if the observed atmospheric column contains "enough" water vapour ($H_2O^{VCA} > 1.14$ gcm^{-2}). The WFM-DOAS XCO_2 data set suffers from thin and high clouds in the tropics especially in the Southern Hemisphere, as shown by Heymann et al. (2012). For this reason, this filter approach is an appropriate extension to the existing cloud filtering criteria."

Referee: *"The reference O2 column is determined from the US standard atmosphere." (p.4294, l.10) Does this imply that meteorology ie. high- and low-pressure systems are not considered to calculated the O2 column for each individual sounding? One might wonder if deviations between reference O2 and retrieved O2 at least partially originate from wrong reference O2 due to this crude assumption."*

Authors: In order to be consistent with Schneising et al. (2011), we determined the reference O_2 column from the US standard atmosphere by considering the surface elevation. We mentioned this by: "The reference O_2 column is determined from the US standard atmosphere O_2 column by accounting for the surface elevation variations in order to obtain the same O_2-ratio as used by Schneising et al. (2011)."

Deviations from the reference O_2 column due to pressure systems of less than 5 % are expected for most of the data. The O_2-ratio based cloud filter allows deviations from the reference O_2 column due to low pressure systems of 10 % and due to high pressure systems of 5 %. This means, that in most cases cloud-free measurements influenced by low and high pressure systems are not classified as cloud contaminated.

Referee: *"Equation (2) aims at correcting errors in XCO2 due to aerosol- and cloud-related errors in retrieved O2. The main reason to retrieve O2 simultaneously with CO2 is to correct for aerosol- and cloud-related errors in XCO2 by ratioing (p.4290,l.21). Either equation (2) is actually undoing the O2 lightpath correction or the O2 lightpath proxy does not work and one could have calculated XCO2 with reference O2 in the first place (if it was meteorologically correct, see previous comment). Please seriously examine the approach (or the wording if I misunderstood things)."*

Authors: We discussed the usage of a reference O_2 column for the normalisation of the CO_2 column in the revised version of the paper in the following paragraph: "We have performed various simulations to study the relation of XCO_2 and the O_2-ratio in the presence of thin clouds and aerosols. We found a strong and nearly linear dependency of XCO_2 on the O_2-ratio for simulation scenarios (same default scenario as in Sect. 4.1.1) with different SZA, surface albedos and COD. The reason for this dependency are different sensitivities of the radiances (different light paths) to scattering by aerosols and thin clouds in the spectral regions used for the retrieval of the O_2 and CO_2 columns. Therefore, we have investigated if a reference O_2 column, obtained from ECMWF (European Centre for Medium-Range Weather Forecasts) surface pressure and used for the normalisation of the CO_2 column, improves the quality of the XCO_2 data product. However, we find large regional patterns, a much larger intra-monthly scatter, larger seasonal cycle amplitudes and significant lower yearly increases over the Northern and Southern Hemisphere. Overall we find, that using a reference O_2 column reduces the quality of the SCIAMACHY WFM-DOAS XCO_2 data product. This indicates, that using the retrieved O_2 column for the normalisation of the CO_2 column reduces in most cases retrieval errors."

Referee: *"8 locations are selected to estimate a monthly regional-scale scatter and a single measurement precision. How are these stations selected? Are they representative of geophysical variability or are they potentially challenging regions for the algorithm?"*
Authors: In order to clarify this in the paper, we added the following: "We have selected the same locations as used by Heymann et al. (2012). For these locations sufficient XCO_2 data are available and they are distributed over all continents covered by the data."

Referee: *"Figure 7 shows exemplary seasonal mean WFM-DOAS and CarbonTracker XCO2. I suggest showing differences between WFM-DOAS and CarbonTracker which would save half of the panels and give more relevant insight. Further, I suggest showing additional exemplary maps for fall and winter. Why are the datasets smoothed by a 2D-Hann window (figure caption)? Seasonal averaging on 0.5deg x 0.5deg should be sufficient to remove statistical error components. Additional smoothing operations are to justify in the manuscript."*
Authors: We aim at showing the XCO_2 increase (between 2003 and 2009), the northern hemispherical carbon uptake between spring and summer (seen by the high XCO_2 values between April and June and the low XCO_2 values between July and September) and the coverage of the WFMDv2.2 XCO_2 data product. The northern hemispherical carbon uptake can not be shown by comparing maps of fall and winter. Therefore and in order to save space, we decided not to show this figure.

In comparison with the CarbonTracker maps, the main regional differences can also be seen, e.g., over the Horn of Africa and over India, which are already mentioned in the paper. For this reason, a difference map would only give little new insight.

In order to justify the smoothing, we added the following sentences: "We have gridded the data on a $0.5^\circ \times 0.5^\circ$ latitude/longitude grid. Furthermore, we have smoothed the data by using a 2D-Hann window with a width of 20 × 20 (10° × 10°) because some grid boxes have not sufficient data to remove the statistical error."

Technical Corrections

Referee: *"Abstract: The abstract is too long. Its first part reads like an introduction."*
Authors: We shortened the abstract.

Referee: *"p.4288, l.1: Avoid extensive self-referencing."*
Authors: Done.

Referee: *"p.4288, l.17: Important references missing eg. Oshchepkov et al., Connor et al., Yoshida et al."*
Authors: Additional references were added in the revised version of the paper.

Referee: *"p.4290, l.6 and elsewhere: integration time -> exposure time"*
Authors: "Integration time" is SCIAMACHY nomenclature and was used in several publications (e.g., Bovensmann et al. (1999); Barkley et al. (2007); Buchwitz et al. (2005)).

Referee: *"section 3: The algorithm description lacks a short paragraph on how aerosols are treated."*
Authors: We included the following paragraph: "Aerosols are considered by using a constant aerosol vertical profile for the radiative transfer simulations. In addition, the aerosol variability is considered (i) by using O_2 as light path proxy, (ii) by the low-order DOAS polynomial which makes the retrieval insensitive to spectrally broadband radiance modifications, and (iii) by using the SCIAMACHY Absorbing Aerosol Index (AAI) data product (Tilstra et al., 2007) to identify and filter scenes contaminated with high loads of aerosols."

Referee: *"Table 2: Merge with table 3."*
Authors: Done.

Referee: *"Figures: Most figure legends lack units."*
Authors: Done.

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