Authors' answer to the interactive comments of anonymous referee #1 on paper Heymann et al., Atmos. Meas. Tech. Discuss., 5, 2887-2931, 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.

Specific Comments

Referee: *"Section 4.3: Why did you take monthly means for CALIOP data, and not the daily product to then co-locate SCIAMACHY retrievals? Were there not enough SCIAMACHY data? The way you are doing currently, I can imagine that the true variability of cirrus is smoothed out a lot."*
Authors: We use monthly means because we aim to investigate systematic retrieval errors due to scattering by aerosols and thin clouds. The statistical error of the retrieved XCO_2 is reduced by using monthly averages for the temporal analysis and a $1^\circ \times 1^\circ$ grid for the spatial analysis.

We use cloud statistics based on CALIOP measurements because there are not enough co-locations with SCIAMACHY measurements to use a daily product due to the narrow swath width of CALIOP (70 m) compared to SCIAMACHY (960 km). In addition, a co-located single CALIOP measurement can not give information about cloud cover and optical depth within the entire SCIAMACHY pixel. The typical size of a SCIAMACHY pixel is 30 km by 60 km. In comparison, a CALIOP pixel is 5 km by 70 m (the SCIAMACHY pixel is about 5000 times larger). These will be mentioned in the revised version of the paper.

Referee: *"Section 5.2: Can you comment on these results and the various correlations between the uncorrected and corrected datasets ; what do your learn from it? There is a clear seasonality in the correction term $XCO_2^{S^*-S}$ shown in Fig. 9 for Southern Africa. Is it expected, does the scan angle depend on seasons? In general, I fail to see how relevant it is to quote the correlations (and without commenting these numbers) between the different terms: it could be, for instance, that your correction $XCO_2^{S^*-S}$ is seasonal just because of viewing angle geometry; and that the residual $XCO_2^{S^*-C}$ is also seasonal due to for instance seasonality of cirrus or wrong seasonal cycle in CarbonTracker; you would see a correlation between the two terms but there could be no physical link behind these two facts."*
Authors: As shown by the correlations between $\Delta XCO_2^{S^*-C}$ and ΔXCO_2^{S-C} in Tab. 3, the scan-angle-correction does not change the phase of the seasonality of the SCIAMACHY and CarbonTracker difference. Only the amplitude of the seasonality is reduced in most regions as

shown by the smaller standard deviations of $\Delta XCO_2^{S^*-C}$ compared to the standard deviations of ΔXCO_2^{S-C}.

The strong anti-correlation between $\Delta XCO_2^{S^*-S}$ and ΔXCO_2^{S-C} in most regions shows that the scan-angle-correction can be responsible for a large part of the difference between SCIAMACHY and CarbonTracker (also shown by the reduced standard deviations).

A discussion about the seasonality of $\Delta XCO_2^{S^*-S}$ will be added to the revised version of the paper in the following way: The seasonality of the scan-angle-bias correction in Southern Africa, as shown by the time series of $\Delta XCO_2^{S^*-S}$ can be explained by the following: The scan-angle-bias correction depends only on the viewing zenith angle (VZA) (see Eq. 2). This means, that a seasonality of the scan-angle-bias correction is due to a seasonality of the VZA, which originates from the quality filtering. In the winter months (large SZA), more measurements under "large" VZA conditions are filtered out than in summer (small SZA). This may be related to a higher sensitivity under "large" SZA and "large" VZA conditions (longer light path) to scattering by aerosols and clouds and/or larger noise of the spectra. Together with the VZA asymmetry of the scan-angle-bias correction (Eq. 2 and Fig. 6), this can result in the observed seasonality.

Referee: *"Actually I was wondering if you could not used TCCON as a reference for seasonality, as CarbonTracker often underestimates the seasonal cycle in the northern hemisphere? This is just a suggestion."*

Authors: The SCIAMACHY XCO_2 data set covers the years 2003 – 2009. In this period only 4 – 8 TCCON stations can be used for our analysis (the TCCON stations used by Schneising et al. (2012)). These stations are not representative for all regions of the globe (e.g., measurements over Africa, South America and Asia are missing). For this reason and for the reason that we want to compare SCIAMACHY with CarbonTracker XCO_2 (which needs significant averaging to minimise the statistical error), we decided to use larger regions.

Figure 1 of Schneising et al. (2012) also shows that the difference between the FTS measurements and CarbonTracker are not as large as the difference to the SCIAMACHY measurements (shown, e.g., for Park Falls and Darwin).

Referee: *"Regarding your analysis in the TCCON surroundings: you find a scatter of 7.4 ppm in the monthly XCO2 dataset but say that Schneising et al (2012) find a regional precision of 2.1 ppm. Where does the large difference between these two numbers come from? I understand that those are two very different studies, but still I'm surprised. Does that come from the strong XCO2 seasonal cycle that makes monthly means not appropriate for the estimation of standard deviation?"*

Authors: The two numbers represent different things and are not directly comparable. Schneising et al. (2012) used the standard deviation of the differences to the TCCON FTS measurements of monthly averaged data and compute the overall mean. We use the intra-monthly standard deviations and compute the overall mean. This is equivalent to averaging the vertical bars on the SCIAMACHY data in Fig. 1 of Schneising et al. (2012). In other words, one estimate is a feature of the monthly averaged data and the other is a feature of single measurements within a given month. We will clarify this in the revised version of the paper.

Referee: *"Section 6.2: I would like to see more discussion about your results. For instance, some of the differences between CarbonTracker and SCIAMACHY show a strong seasonality: it could come from the CarbonTracker data itself, which seasonal cycle is not accurate (indeed you mention it but I would emphasize this point a bit more), from seasonality of cirrus or aerosols but also from other parameters that vary with seasons: SZA or airmass, albedo, ..."*

Authors: We will present a more detailed discussion in the revised version of the paper. The analysis results section will be extended in the following way (changes are shown in bold):

The results of the temporal and spatial correlation analysis for China are shown in Fig. 11. The amplitude of the seasonal cycle is larger for SCIAMACHY compared to CarbonTracker. To a minor extent ($r^2 = 9.2\,\%$), the difference may be due to retrieval errors caused by thin clouds. The spatial analysis shows that in autumn 33 % of the variability of $\Delta XCO_2^{S^*-C}$ may be explained by eCOD, i.e. clouds related retrieval errors. The AOD over China is the highest of all investigated regions, therefore one would expect to find also the largest correlation. However, this analysis only shows low temporal and spatial correlations with aerosols. This may indicate that aerosols are not a significant problem for the WFMDv2.1 algorithm in this region. On the other hand it needs to be considered that CarbonTracker is not perfect. For example, there are indications that the underlying CASA (Carnegie-Ames Stanford Approach) biosphere model underestimates the net ecosystem exchange (NEE) between the atmosphere and the biosphere (Yang et al., 2007; Schneising et al., 2011; Keppel-Aleks et al., 2012; Messerschmidt et al., 2012). **In order to investigate the impact of this underestimation on the results, we have performed the same analysis with a 40 % scaled CarbonTracker amplitude for all regions. We found that the correlations are similar for most regions and the conclusions are the same as for the unscaled CarbonTracker amplitude.**

Figure 12 shows the corresponding results for Southern Africa. As can be seen, the amplitude of the difference is about 4 ppm. Neither a "U-shape", as mentioned by Schneising et al. (2008) for the seasonal cycle of the southern hemispheric WFMDv1.0 XCO_2, nor an evident phase shift between the seasonal cycle of $XCO_2^{S^*}$ and XCO_2^{C} can be seen in this region. However, Fig. 12 shows that 31 % of the temporal variability of $\Delta XCO_2^{S^*-C}$ may be explained by thin clouds. **A larger temporal correlation ($r^2 = 55\,\%$) has been found for the time period 2007 – 2008 (the cloud statistics are based on CALIPSO measurements from these years).** The temporal correlation of $\Delta XCO_2^{S^*-C}$ with aerosols is statistically not significant in this region. The spatial correlation analysis shows that there are some correlations between $\Delta XCO_2^{S^*-C}$ and eCOD and also with AOD. The largest influence of clouds and aerosols on the difference is during spring (MAM).

The corresponding results of the spatial and temporal correlation analysis for all regions investigated are summarised in Table 5. Many regions over the Northern Hemisphere show low spatial correlations ($r^2 < 25\,\%$). **Due to high aerosol loads not only in China, as can be seen by the yellow to red areas in Fig. 4, e.g., over Africa, Southern Africa, Arabia and India, one would expect high spatial and temporal correlations over these regions. However, the only regions, where large spatial correlations can be found are Arabia (35 % during summer), Africa (26 % during summer) and Southern Africa (34 % during spring). A large temporal correlation with aerosol can only be found for India (54 %). Large spatial correlations with thin clouds are more rarely expected than temporal correlations, e.g., due to the significant spatial smoothing of the CALIPSO data. In addition, the smoothed cloud data is based only on CALIPSO observations from the years 2007 – 2008. However,** large spatial correlations with thin clouds are found over the Northern Hemisphere, e.g., for Africa during spring (MAM). For the Southern Hemisphere, the spatial correlations with thin clouds often exceed 25 %. The largest spatial correlation is found for Australia (48 % during DJF) indicating that a large part of the spatial variability of the XCO_2 difference in this season can be explained by thin clouds.

Temporal correlations with eCOD are typically large for several regions over the Southern Hemisphere and typically low over the Northern Hemisphere with the exception of India. **Figure 5 shows that thin clouds often occur in the tropics. Therefore, one would expect the largest impact of thin clouds on the XCO_2 difference over tropical regions. This is confirmed by the correlations over India and especially over the Southern Hemisphere (most of the landmasses of the Southern Hemisphere are in the tropics).** The results also corroborate the assumption of Schneising et al. (2011) that the differences between SCIAMACHY WMFDv2.1 and CarbonTracker XCO_2 over the Southern Hemisphere are likely due to unaccounted thin clouds. The low temporal and spatial correlations with aerosols for many regions show that aerosols likely only marginally contribute to the observed difference to CarbonTracker.

***Referee**: "Also, what does that mean when you find for some regions a strong temporal correlation with cirrus and/or aerosol but a weak spatial correlation? I would tend to say that you can only conclude on the source of errors when you find both, a temporal and spatial correlation with aerosol and/or cirrus."*

Authors: Spatial correlations are more rarely expected than temporal correlations, for example, due to the significant spatial smoothing of the CALIPSO data. In addition, the smoothed cloud data is based only on CALIPSO observations from the years 2007 – 2008. This may explain why often high temporal correlations are found but only low spatial correlations. These will be mentioned in the revised version of the paper.

Referee: *"Finally, in Table 5, I don't understand the high temporal correlation with aerosol on the global scale, whereas it is very small for Northern Hemisphere or Southern Hemisphere taken separately."*
Authors: This comment is similar to one of the comments of A. Galli and we repeat our answer here:
The intention also showing the results of the correlation analysis for the global and hemispheric scale in Tab. 5 was for the sake of completeness. However, we are careful with the interpretation of the results for these very large regions for the following reason:

Our method requires an appropriate size of the regions. The regions should be large enough to reduce the statistical error but not too large, e.g., due to too large spatial variations. Very likely the global and the NH and SH are too large for our method and too difficult to interpret. Therefore, we will remove the results of the correlation analysis for the global and also for the NH and SH from Tab. 5.

Technical Corrections

All technical corrections will be considered in the revised version of the manuscript.

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