Author's reply to Referee #2

First of all, we would like to thank the referee for constructive and thoughtful comments which helped us to improve the manuscript. We are also grateful for technical corrections and we will adopt most of the suggestions in the final version of the manuscript (amt-2015-364).

Point-by-point response to specific comments and technical suggestions:

Referee: Page 1 line 6: The fundamental band of CO is referred to as the 4.5 μm band – I have always seen it referred to as the 4.7 μm band which more correctly represents the band centre of 2140 cm^{-1}. This occurs in several places in the manuscript.

Author: We will replace *"4.5 μm band"* by *"4.7 μm band"* throughout the manuscript.

Referee: Page 2 line 4: The authors talk about the ground-based data providing the same quantities as measured by the satellite. However in practice the satellite and the ground-based measurements are different – as evidenced by different weighting functions and averaging kernels (AKs) – and so the comparison almost always requires significant interpretive work to accomplish. The sentence should be revised.

Author: We will rewrite the sentence:

"These measurements are confirmed and validated by ground-based data records which provide similar quantities as measured by satellite-borne instruments (de Laat et al., 2010). Nevertheless, validations and comparisons of retrieval results from different remote sounders are not straightforward and still require additional mathematical methods as well as significant interpretive work (Rodgers et al., 2003[1])."

Referee: Page 2 line 9-10: No instrument actually provides a column amount of a constituent – that would require an AK that was invariant with height. We can provide column estimates given certain assumptions, but not true column amounts. Since the variations in the AKs are significant in this paper, this should be clarified.

Author: We will rewrite the sentence:

"The TCCON approximates column averaged abundances of several atmospheric gases which are subject to the usual restrictions of the remote sensing technique, e.g. non-perfect averaging kernels and a priori knowledge."

Referee: Page 2 line 16: Many satellite instruments (e.g. IASI, MOPITT, TES, AIRS) use the fundamental band of CO for their measurements.

Author: We will weaken the statement and rewrite the sentence:

"TCCON CO retrievals are done from the 2.3 μm overtone absorption band, the same band which is used for retrievals of data sets measured by e.g. the Scanning Imaging Absorption Spectrometer for Atmospheric Cartography (SCIAMACHY, Bovensmann et al., 1999[2])."

Referee: Page 3 Lines 15-17 and Page 6 lines 25-27: According to page 3 the spectral ranges of the detectors imply that the overtone band of CO is measured by the InSb detector but page 6 implies that it is done by the InGaAs detector. These points should be reconciled.

Author: We will change Page 6 lines 25-27 to:

"Typically, we alternately record spectra by using different narrow band filters mounted in front of the InSb diode while simultaneously recording NIR spectra with the InGaAs diode. However, the narrow band filters in front of the InSb diode are shuffled in an order that every other spectrum covers the CO first overtone band leading to a larger number of TCCON-style CO measurements than NDACC-style measurements covering the fundamental band."

Referee: Page 3 line 22: the text implies that there is a choice of bands for CO. The only CO band in the MIR is the fundamental and the only one in the NIR is the first overtone – there is virtually no choice in what bands to use.

Author: We agree and will change the sentence to:

"Additionally the fundamental absorption band of CO lies in the covered spectral range."

Referee: Page 4 line 27: the source of the eight profiles is not mentioned – are these radiosonde ascents or reanalysis products or something else?

Author: The pressure and temperature profiles are taken from measurements obtained from instruments installed at the Karlsruhe meteorological tall tower (200m) and the MERRA (Modern-era retrospective analysis for research and applications) model data "IAU3D assimilated state on pressure (inst3_3d_asm_CP)" which provides temperature and pressure profiles on a 1.25° × 1.25° grid, from 1000 to 0.1 hPa for 8 times per day. For each of the 8 time points, the solar position is calculated and the pressure and temperature along the unrefracted path of the solar radiation are retrieved from the model data. A detailed description is given in Gisi et al. (2012)[3]. We will add these information to section 3.1.

Referee: Page 5 line 20: I think that a minus sign got into equation 3. The denominator of the first term is dimensionally inconsistent as written.

Author: We will remove the minus sign in the denominator of the first term of equation 3.

Referee: Page 6 lines 1-9: The discrepancy between the total dry air column derived from the ground pressure and that derived spectroscopically is troubling. The error appears to be constant and so cannot be due to the water vapour correction. The bias is significant and warrants some careful investigation.

Author: The discrepancy between the total dry air column derived from the ground pressure and that derived spectroscopically is mainly due to spectroscopic inadequacies attributed to oxygen line intensity errors rather than from the water vapour correction in the derivation of the total dry air column from the ground pressure. A constant bias of -2.28 % is in good agreement with a bias of -2.27 % observed by Washenfelder et al. (2006)[4]. Nevertheless, we use spectroscopically derived

total dry air columns to calculate XCO from MIR spectra to achieve a more consistent comparison to TCCON measurements which also use spectroscopically derived total dry air columns which are not bias corrected. However, despite the constant bias, the advantage of Eq. 2 is that errors in retrieved total columns of H_2O and inadequacies in measurements of the ground pressure do not contribute to the total dry air column. Moreover, errors that are common to CO and O_2 are minimized, e.g. mis-pointing of the solar tracker and zero-level offsets. We will clarify this in the final version of the manuscript.

Referee: Page 6 line 9: Surface pressure measurements at high accuracy are relatively easy to make, the references to "inadequacies in measurements of the ground pressure" are somewhat surprising.

Author: We will weaken our statement and rewrite:

"… and rare but still possible inadequacies in measurements of the ground pressure due to instrument failure…"

Referee: Page 7 line 22: Figure 16 does not reflect the text as it does not vary the slant column.

Author: We will adjust the sentence such that:

"Accordingly, this effect is revealed by depicting the CO slant column and its change for different line lists, see Fig. 16 in Appendix A."

Referee: Page 8 lines 5-15: In this section we have reference to several correction factors that seem to verge on the empirical. If comparisons between datasets are to have validity, then these differences need to be explained – which is the main point of this paper.

Author: TCCON measurement are tied to the WMO scale by dividing DMFs of the target gas by an airmass-independent correction factor determined via in situ measurements over TCCON sites. Such a scaling is reasonable since the observations rely on spectroscopic parameters which might contain systematic biases (e.g. for line intensity parameters). Within the NDACC, no post processing scaling is applied. Since the TCCON in situ calibration factor is about 7 %, it is the major source which contributes to the observed bias and should be taken into account when comparing NDACC and TCCON CO data.

Referee: Page 1 line 3: "…allows us to record…"

Author: We will write: *"…allows us to record…"*

Referee: Page 1 line 11: "…XCO can be explained by the smoothing effect…"

Author: We will weaken the suggestion by the author and will write: *"…XCO can be largely explained by the smoothing effect…"*

Referee: Page 5 line 24: "…FTIR setup allows us to record…"

Author: We will write: *"…FTIR setup allows us to record…"*

Referee: Page 11 line 20: "…might be due to imperfect knowledge of the spectroscopic parameters…"

Author: We will write: *"…might be due to imperfect knowledge of the spectroscopic parameter in the MIR and NIR."*

Referee: Figures: I found that the figures were hard to read – the lighter blue dots on a grey background with white grid lines was difficult to interpret. The figures also should be understandable in black-and-white as well as color through the use of different symbol shapes or some similar mechanism.

Author: We will adjust the color of the lighter blue dots and apply different symbol shapes where it seems appropriate in the final version of the manuscript.

References:

[1] Rodgers, C. D., and B. J. Connor (2003), Intercomparison of remote sounding instruments, J. Geophys. Res., 108, 4116, doi:10.1029/2002JD002299, D3.

[2] H. Bovensmann, J. P. Burrows, M. Buchwitz, J. Frerick, S. Noël, V. V. Rozanov, K. V. Chance, and A. P. H. Goede, SCIAMACHY: Mission Objectives and Measurement Modes, Journal of the Atmospheric Sciences 1999 56:2, 127-150 .

[3] Gisi, M., Hase, F., Dohe, S., Blumenstock, T., Simon, A., and Keens, A.: XCO2-measurements with a tabletop FTS using solar absorption spectroscopy, Atmos. Meas. Tech., 5, 2969-2980, doi: 10.5194/amt-5-2969-2012, 2012.

[4] Washenfelder, R. A., G. C. Toon, J.-F. Blavier, Z. Yang, N. T. Allen, P. O. Wennberg, S. A. Vay, D. M. Matross, and B. C. Daube (2006), Carbon dioxide column abundances at the Wisconsin Tall Tower site, J. Geophys. Res., 111, D22305, doi:10.1029/2006JD007154.