Author's reply to Referee #1

First of all, we would like to thank the referee for helpful comments and suggestions. We will adopt most of the suggestions in the final version of the manuscript (amt-2015-364). We are also grateful for pointing out minor corrections to improve clarity of the manuscript and figures.

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

Referee: Analysis procedures, section 3.1: What are the a priori covariances and assumed measurement signal to noise? These have direct impact on the retrieval stability, averaging kernels, and dofs. Is this outlined in Kramer's PhD thesis (which is not readily available online)?

Author: The procedure used for the NDACC CO retrieval is a constrained profile retrieval similar to the retrieval strategy described by Sussmann et al.[1] for CH_4. We use a first order Tikonhov-Phillips regularization on a logarithmic scale. Instead of using a priori covariances, the regularization term is $R = a\ L_1{}^T L_1$ with L_1 the discrete first order derivative operator and a the regularization strength. The signal-to-noise ratio is empirically obtained from the fit residual and the regularization strength a is tuned in a way such that dofs ≈ 3 are reached. We will complement section 3.1 by adding these information.

Referee: While the xCO air mole fractions reported have precisions reported, there is not any discussion or mention of the typical errors associated with a CO column estimate from both analysis methods per spectra. Are they similar? The NDACC spectra have inherently higher spectral noise due to the larger OPD; is this an issue? The CO fundamental band line at 2157 cm^{-1} is very strong, whereas both of the CO lines in the overtone are much weaker, and subject to more interference from other absorbers and solar CO. Are these effects important?

Author: For the error estimation associated with the CO columns, we follow the approach described in Schneider et al.[2] and Schneider et al.[3] using the operational error estimation capability of PROFFIT. Error sources taken into account are the offset in the spectrum zero baseline, solar zenith angle, ILS (modulation and phase), spectroscopic errors/interfering species/ solar lines, line of sight and temperature. We assume a baseline offset uncertainty of 0.1 %, a modulation efficiency uncertainty of 1 %, a phase error of 0.01 rad. We assume the same spectroscopic errors for the target gas and interfering gases, namely 2 % uncertainty in line strength and 5 % in the air pressure broadening coefficient. We assume a solar line strength uncertainty of 1 %. The error contributions are used for establishing an estimate of statistical and systematic error budgets. We performed a case study for the error estimation for one particular Karlsruhe spectrum recorded in the MIR and NIR in summer 2014. In the MIR, the total systematic error is ~ 2 % with a total statistical error of ~ 0.5 %. In the NIR, we obtain a systematic and statistical error of ~ 3 % and ~ 1.5 %, respectively. The interfering species in the MIR contribute with ~ 0.35 % to the total systematic error whereas in the NIR, where the CO lines are weaker and subject to more interference from other absorbers, the contribution is ~ 1 % which is supported by larger residuals in the NIR compared to the MIR (see Fig. 2 and Fig. 3). In consequence, this leads to a higher overall systematic error in the NIR. The noise error in the MIR and NIR is ~ 0.3 % and ~ 1 %. We also report the smoothing error, which has to be taken into account due to the limited vertical resolution of remote sensing systems. We obtain a smoothing error of ~ 0.2 % for the MIR retrieval while the smoothing error in the NIR is ~ 1.5 %. The larger error in the NIR is due to the retrieval strategy that only allows for a scaling of the a priori profile. Both error values support our findings in section 3.4 where the impact of varying a priori profiles on retrieved column abundances was analyzed for both retrieval strategies.

Referee: 4.2.1: suggest writing the averaging kernel symbol as ($A_{MIR\text{-}NIR}$)

Author: We will change the averaging kernel symbol to ($A_{MIR\text{-}NIR}$).

Referee: Figure 1. The TCCON a priori has very low CO mixing ratios above 50 km or so. This is only 1% of the column that is effectively missing, but this might account for some of the sharp features in the residual of figure 3. This probably does not affect the biases, but it might account for the shape of the TCCON averaging kernel significantly over weighting in the upper atmosphere.

Author: We performed a case study (for one particular Karlsruhe spectrum recorded in the NIR) and modified the TCCON a priori profile above 40 km by increasing the VMR, similar to the WACCM profile used for the NDACC retrieval (see Fig. 1). The residuals are depicted in Fig. 2 and still contain sharp features around 3 % for both spectral windows. Therefore we do not think that sharp features in the residuals are due to the shape of the a priori profile above 40 km.

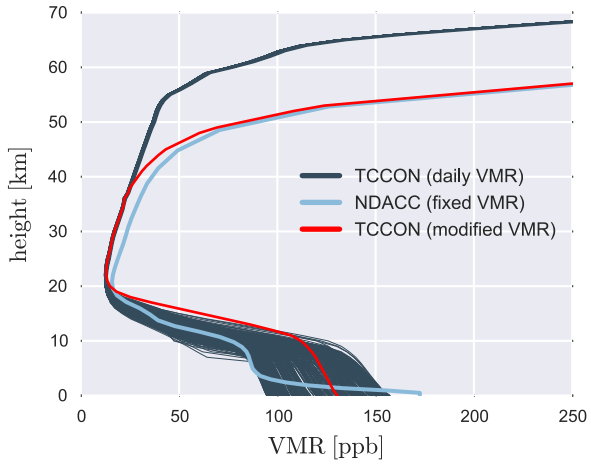

Fig.1: Modified TCCON apriori profile

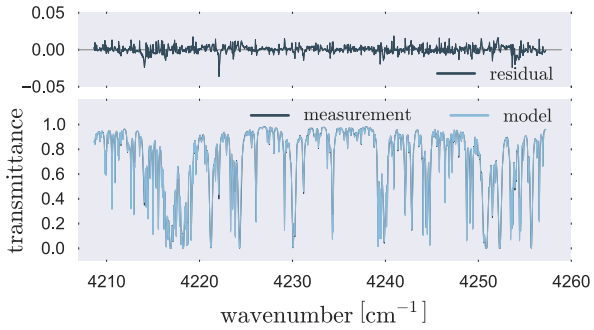

Fig.2: Spectral fit and residuals for the CO (4208.7 – 4257.3) cm^{-1} spectral window

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Referee: Figures 2 and 3. It would be instructive for readers not familiar with the spectroscopy to identify the absorbers in the spectra. Why are the residual axes scaled to 5 %, much higher than the noise. Is this driven by the scaling in figure 3 which has a couple of features around 3 %?

Author: For better comparability of residuals from both retrieval strategies, the scaling of the axis in Fig. 2 is set to 5 % which is driven by the scaling in Fig. 3, which has a couple of features around 3 %. The absorbers and interfering gases are listed in Table 1 in the manuscript. We are concerned that the identification of the absorbers in a wide spectral windows as used for the TCCON retrieval (Fig. 3) would lead to a complex and crowded/overfull figure and therefore we would like to renounce the identification of the absorbers in both figures.

Referee: Fig. 9 and Fig. 13: the data labelled "original" is a little confusing at first. Perhaps an explicitly reference to what this actually means in the legend.

Author: We will add a reference in the legend of Fig. 9 and Fig. 13 which describes the label 'original' in the following way: *The unmodified standard retrievals as used for NDACC and TCCON are labelled 'original'* .

Referee: Figures 17 and 18 are not referred to all in any discussion. Why are they there?

Author: Figure 17 and Fig. 18 are discussed in section 4.1 (p.8 l.16ff) where the impact of the airmass-dependent correction factor (AD) is analyzed.

References:

[1] Sussmann, R., Forster, F., Rettinger, M., and Jones, N.: Strategy for high-accuracy-and-precision retrieval of atmospheric methane from the mid-infrared FTIR network, Atmos. Meas. Tech., 4, 1943-1964, 2011.

[2] Schneider, M., Toon, G. C., Blavier, J.-F., Hase, F., and Leblanc, T.: H2O and δD profiles remotely-sensed from ground in different spectral infrared regions, Atmos. Meas. Tech., 3, 1599-1613, 2010.

[3] Schneider, M., Sepúlveda, E., García, O., Hase, F., and Blumenstock, T.: Remote sensing of water vapour profiles in the framework of the Total Carbon Column Observing Network (TCCON), Atmos. Meas. Tech., 3, 1785-1795, 2010.