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D6.3

Report on the comparability of TCCON measurements with in-situ measurement based column at two sites

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ABSTRACT

A comparison of TCCON observations of column-averaged dry air mole fractions of CO_2 with a combination of tall-tower based in-situ profile observations for the PBL, boundary layer height data, and TM3-simulated CO_2 mixing ratios for the free troposphere.

In general, the dry-air mole fractions retrieved by the different methods (TM3 model, synthetic model + tall-tower in-situ, TCCON) agreed within limits. The model-derived columns are likely biased high vs. TCCON during winter and also possibly during summer. One possible reason could be that the age of air in the stratosphere is too low in the TM3 model. This would lead to overestimated CO2 values in the upper part of the column.

More surprising was the small difference between CO_2 profiles derived from model + in-situ observations vs. just modelled ones. The original expectation had been that stronger impacts would be found when using in-situ observations from the towers rather than TM3 model output. However, this was only found for Orleans but not for Bialystok.

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1 INTRODUCTION

1.1 Scope and objectives of the document

In Task 6.3, the comparability between ground based total column measurements and in-situ measurements of major greenhouse gases was evaluated. The tall-tower ICOS sites at Bialystok (BIK), Poland, and Trainou/Orleans (ORL), France, provide in-situ measurements of CO_2 and CH_4 at different levels from the ground to 300 m (BIK) and 180 m (ORL). Co-located at these sites are two Fourier-Transform Spectrometers (FTS) of the Total Carbon Column Observing Network (TCCON), which provide column-averaged dry-air mole fractions of CO_2 (XCO_2), CH_4 (XCH_4) and other species.

To make the in-situ measurements comparable to the column measurements, they had to be extended to a synthetic column. Assuming that the largest part of the variability is generated in the Planetary Boundary Layer (PBL), the in-situ measurements were used to generate a PBL profile. In the free troposphere above the PBL and the stratosphere above, modelled CO_2 fields from the TM3 model were used to account for synoptic-scale transport effects.

A critical point was the separation between PBL and free troposphere, which is determined by the boundary layer height (BLH). The MACC-II data assimilation product provides this parameter on a global scale but without local constraints. In addition, mixing height retrievals from a Lidar system located at ORL were also available for part of the time.

The synthetic CO_2 profiles based on in-situ measurements in the PBL and TM3 results above were then converted to a total column and compared to the FTS total-column XCO_2 measurements. Diurnal, synoptic, and seasonal time scales were investigated for the years 2011 and 2012.

This study was limited to CO_2 as this species combines most of the difficulties possibly encountered in comparing column vs. surface measurements.

1.2 Structure of the document

Section 2 gives an overview of the datasets used, with subsections on TCCON data, in-situ data from tall towers, BLH data, simulated CO_2 data, and on how the synthetic CO_2 profiles were assembled. Section 3 presents the results from the different comparisons, including an analysis at different temporal scales (diurnal in 3.2.1, synoptic in 3.2.2) and an analysis of the impact from in-situ and BLH observations on the comparison (3.2.3 and 3.2.4). Section 4 provides the conclusions.

2 DATA SET DESCRIPTION

2.1 Total column XCO_2 data

Measurements from the TCCON stations Bialystok, Poland (R1), and Orleans, France, (R2) from the years 2011 to 2012 were aggregated onto a 3-hour time grid. The data were taken from the public TCCON data archive. Version GGG2014 was used. The TCCON stations Bialystok and Orleans are colocated with the tall-tower sites Bialystok (BIK) and Trainou (TRN), respectively.

The TCCON network has been calibrated against the WMO in-situ scale by aircraft in-situ measurements. These profiles typically covered the PBL to the top of the troposphere (R3, R4).

2.2 In-situ CO_2 data

In-situ CO_2 and CH_4 data was available from the tall tower sites Trainou (TRN), France, (operated by LSCE) and Bialystok (BIK), Poland (operated by MPI-BGC) (R5). Both stations are equipped with in-situ gas analyzers that are calibrated to WMO standards. The inlets for the in-situ measurements are mounted at

- TRN: 50 m, 100 m, 180 m
- BIK: 4 m, 30 m, 90 m, 180 m, 300 m

The data were aggregated onto a 3-hour time grid.

2.3 Boundary layer height data

Boundary Layer Height (BLH) is key parameter to separate measurements made in the Planetary Boundary Layer (PBL) from the free troposphere. It is not measured regularly at the BIK or TRN station, so a global PBL data product from the Monitoring Atmospheric Composition & Climate (MACC) project had to be used. These were available on a 3-hourly gridded timescale.

During 2011, direct lidar measurements of BLH at TRN were available. These were used as an alternative BLH data set for the comparisons at this site.

2.4 Model CO_2 data

Global analysed fields of CO_2 were available from the MPI-BGC's TM3 inversion system (R6). The data is provided on a 4° latitude by 5° longitude grid on 19 vertical levels. The CO_2 fields were interpolated from their original 6-hour time grid onto the 3-hour time grid of the aggregated measured data.

2.5 Synthetic tower + model-derived column-averaged dry air mole fractions (XCO_2)

To compare the tall-tower measurements to the total column TCCON measurements, the profiles had to be extended from the PBL to the top of the atmosphere. These synthetic profiles were generated by using the in-situ measurements in the PBL and filling the rest of the profile above the PBL from the TM3 model. BLH from the MACC model was used to distinguish between the PBL and the free troposphere.

For Bialystok, the intakes of the tall-tower represented the following altitude ranges above ground:

- intake at 5 m: 0–17.5 m altitude
- intake at 30 m: 17.5–60 m altitude
- intake at 90 m: 60–135 m altitude
- intake at 180 m: 135–240 m altitude
- intake at 300 m: 240–367 m altitude (top of 3rd level in TM3)

Likewise, for Orleans:

- intake at 50 m: 0–65 m altitude
- intake at 80 m: 65–130 m altitude
- intake at 180 m: 130–210 m altitude (top of 2nd level in TM3)

3 RESULTS

3.1 Comparisons between observed and modelled BLH at TRN

In 2011, lidar observations at TRN allowed a direct estimation of BLH above the site. These were used to verify the modelled BLH from MACC that had to be used for the other times and for BIK. **Figure 1** shows a comparison over time as well as the correlation of both data sets. Both the full data set as well as the mid-day values (12:00-15:00 UTC) – where the mixed layer was expected to be fully developed – were compared.

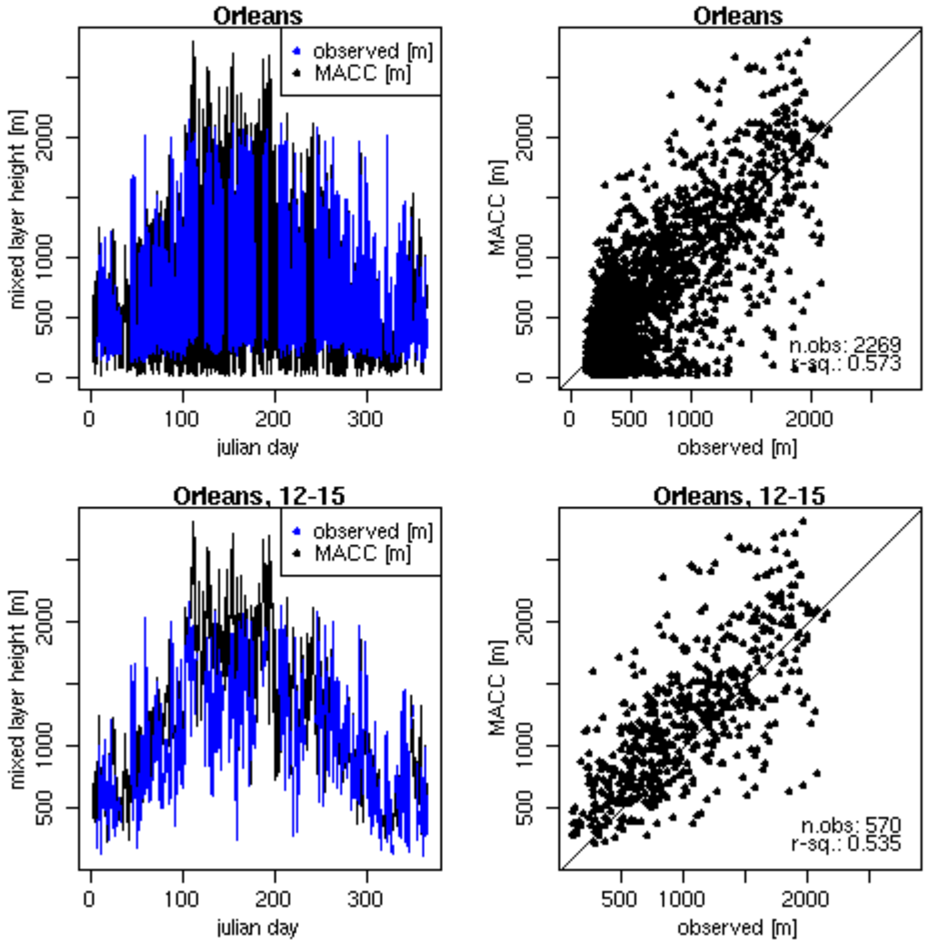

Figure 1: Comparison of observed BLH from Lidar with modelled BLH from MACC at Orleans. Top: full data set. Bottom: only values between 12:00-15:00 UTC.

In general, lower values for BLH during the night and higher values during the day were observed – as expected. The seasonal cycle with higher mid-day BLH in summer was represented well in both datasets (see lower left panel).

The scatter between the two data sets was large and the correlation was only mediocre (with r^2=0.54). There was a slight high bias of modelled BLH from MACC in comparison to BLH derived from Lidar. The uncertainty induced by using MACC BLH is evaluated in this report.

3.2 Comparison between TCCON and tower + model-derived column-averaged dry air mole fractions (XCO_2)

The observed XCO_2 values from the TCCON instruments were compared to the synthetic XCO_2 values derived from the TM3 model + tower observations. **Figure 2** shows the results for Bialystok, both as a time series as well as a scatter plot for the whole dataset. **Figure 3** shows the same for Orleans. Note that these comparisons were only possible for 3-hour time slots with both TCCON as well as tower observations of good quality.

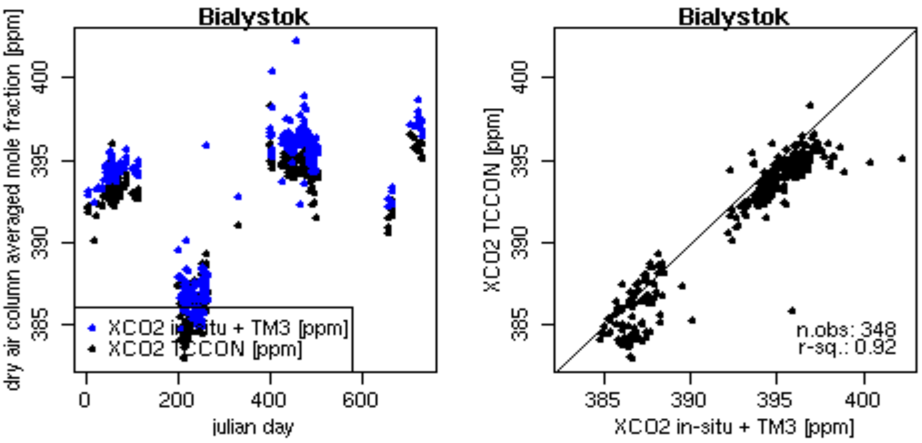

Figure 2: Comparison between TCCON and tower + model-derived XCO_2 at Bialystok for 2011 and 2012. Left: as time series plot for 3-hourly averaged data. Right: as scatter plot.

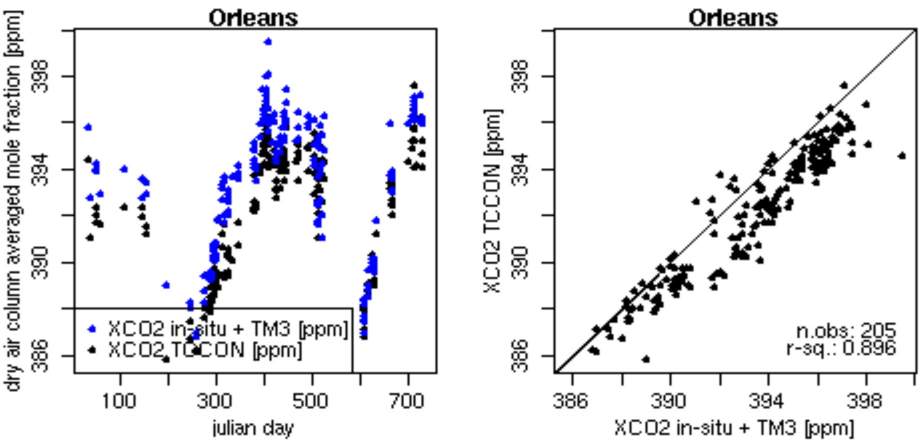

Figure 3: Like Figure 2, but for Orleans.

At Bialystok, large scatter was observed during summer months at lower mixing ratios. The standard deviation of the difference (1-sigma) was 1.13 ppm. The columns derived from the synthetic profiles were biased high by 1.26 ppm compared to TCCON. There was a consistent high bias during winter for the synthetic columns.

At Orleans, the observed scatter between the two data sets was slightly larger. The standard deviation of the difference (1-sigma) was 0.93 ppm. The synthetic columns were biased high by 1.23 ppm compared to TCCON. There was also a consistent high bias during winter for the synthetic columns.

The low bias during wintertime is potentially related to a TM3 high bias due to too fast transport within the stratosphere: too young and CO_2-rich air gets too high into the stratosphere and enhances the upper partial CO_2 column.

3.2.1 Comparisons at diurnal time scales

Diurnal anomalies were computed as differences of individual 3-hourly averaged values and the daily mean value. This was done after selecting days with two or more 3-hour periods with FTIR observations. **Figure 4** shows the diurnal anomalies for Bialystok, **Figure 5** for Orleans.

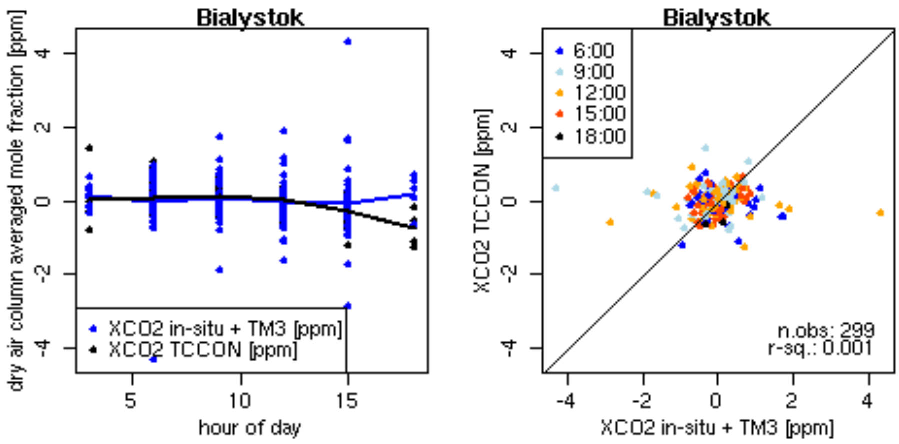

Figure 4: Diurnal anomalies of the synthetic and TCCON-derived XCO_2 for Bialystok. Left: plotted by time of day, lines indicate average anomalies for each 3-hour bin. Right: as scatter plot.

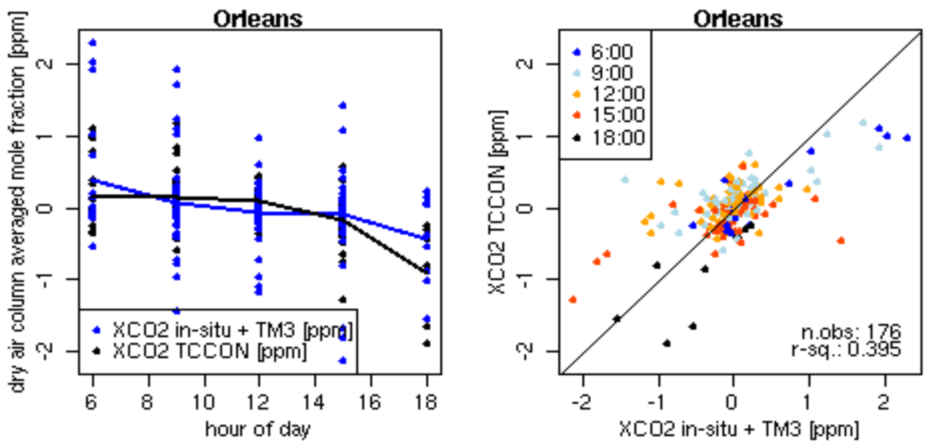

Figure 5: Like Figure 4, but for Orleans.

For Bialystok, there was no correlation between the two data sets (r^2=0.0). The mean diurnal variation was very small in both data sets. At Orleans, there was a weak correlation (r^2=0.4) and a slightly stronger decline in XCO_2 over the day.

3.2.2 Comparisons at synoptic time scales

Anomalies at the synoptic scale were computed as differences of individual daily mean values and a running average taken over a 15-day window. Daily averages were computed after selecting for appropriate (symmetric) coverage around noon to avoid biasing related to the diurnal trend (e.g. decrease over a day during summer time with strong biospheric uptake). **Figure 6** shows the synoptic anomalies for Bialystok, **Figure 7** those for Orleans.

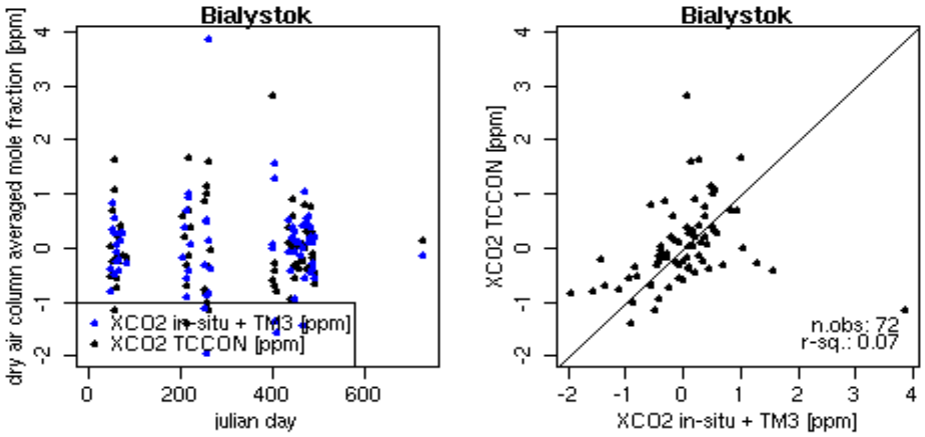

Figure 6: Synoptic anomalies of the synthetic and TCCON-derived XCO_2 for Bialystok. Left: plotted by time of day, lines indicate average anomalies for each 3-hour bin. Right: as scatter plot.

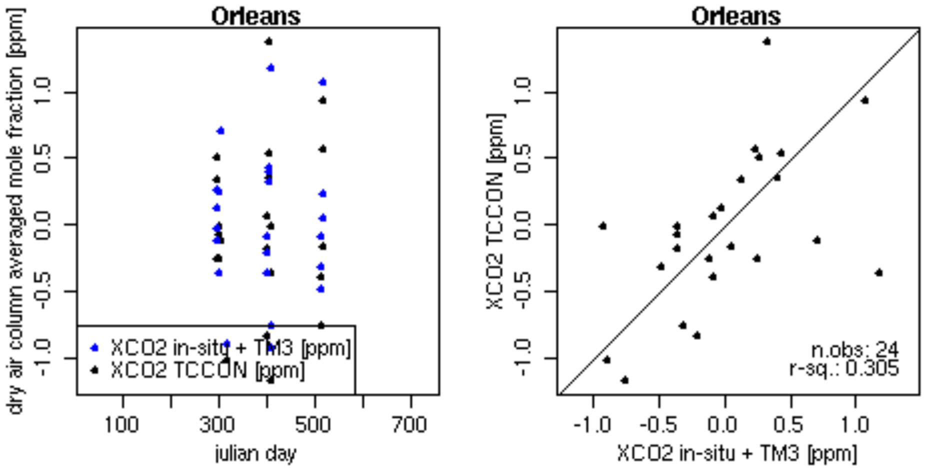

Figure 7: Like Figure 6, but for Orleans.

For Bialystok, there was no correlation (r^2=0.0) and a larger scatter of 1ppm. For Orleans, the correlation was better (r^2=0.3) and the scatter was smaller with 0.5 ppm.

3.2.4 Impact from substituting tower-based observations by TM3-modeled concentrations

To test the impact of the observed tall-tower CO_2 on the synthetic XCO_2, the diurnal and synoptic anomalies from **Figure 4** to **Figure 7** were re-calculated with just the modelled TM3 CO_2 profiles.

Figure 8 shows the diurnal anomalies for XCO_2 derived completely from TM3 model profiles in comparison to those from TCCON at Bialystok. **Figure 9** shows the same for Orleans. **Figure 10** and **Figure 11** show the same for the synoptic anomalies for Bialystok and Orleans, respectively.

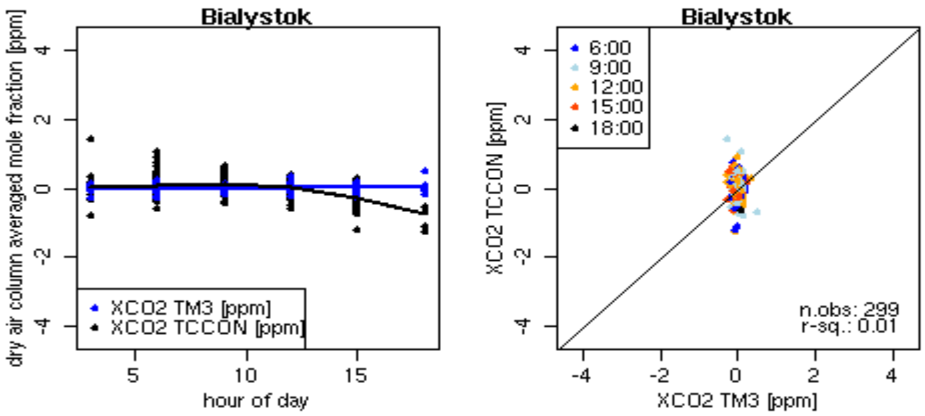

Figure 8: diurnal anomalies at Bialystok like in Figure 4, but using only modelled CO_2 fields to derive column averages.

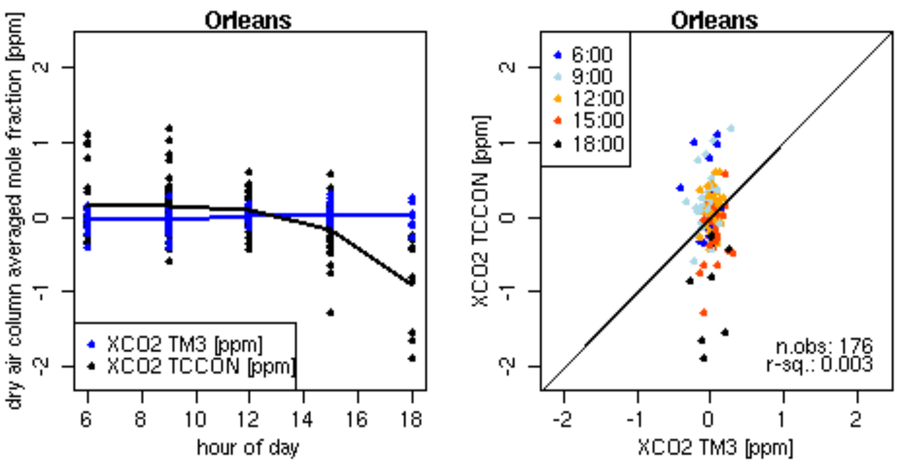

Figure 9: diurnal anomalies at Orleans like in Figure 5, but using only modelled CO_2 fields to derive column averages.

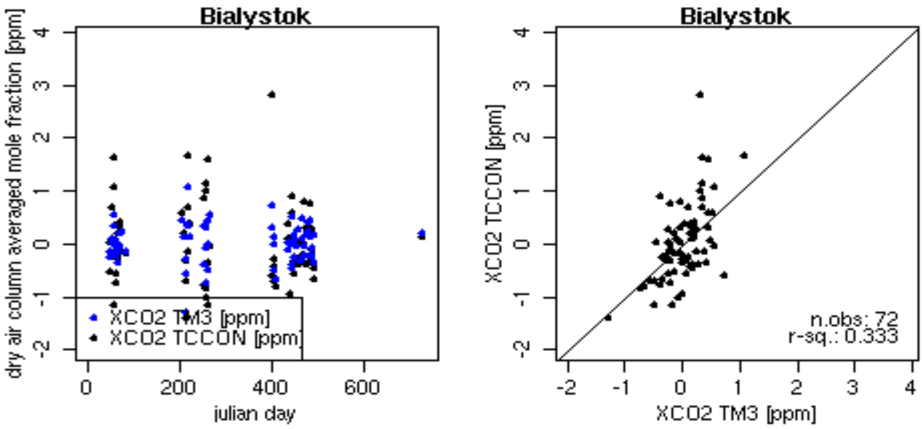

Figure 10: synoptic anomalies at Bialystok like in Figure 6, but using only modelled CO_2 fields to derive column averages.

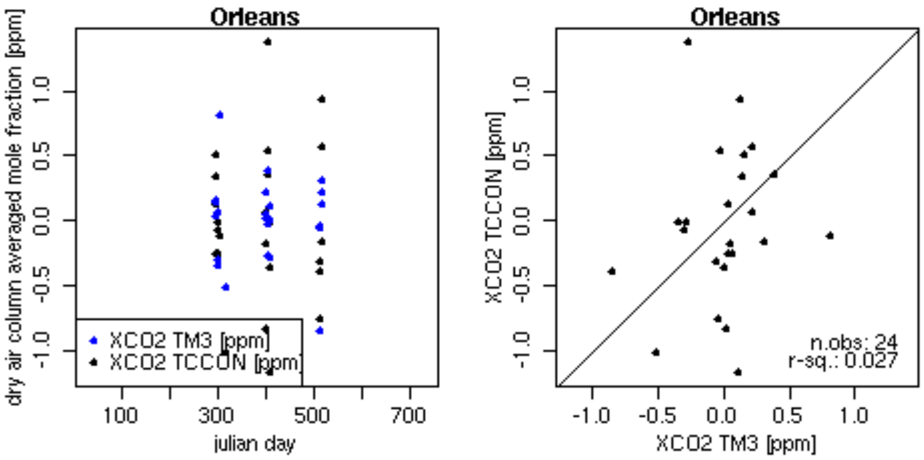

Figure 11: synoptic anomalies at Orleans like in Figure 7, but using only modelled CO_2 fields to derive column averages.

At Orleans, both diurnal and synoptic variations in TCCON-observed columns are better captured when combining tower-based CO_2 profile observations with those profiles extracted from the analysed CO_2 fields. This is indicated by an increase in r^2, but is even more evident in the lack of diurnal trend in the TM3 column. Note that this is not the case at BIK, where r^2 values are generally lower and where the synthetic columns also showed no diurnal trend.

3.2.6 Impact from substituting MACC-based mixing heights by observations

The impact of observed BLH from Lidar measurements vs. modelled BLH from MACC was also assessed. **Figure 12** shows how using either modelled or observed BLH affects the comparisons between synthetic and TCCON-derived XCO_2 for all available Lidar observations during 2011.

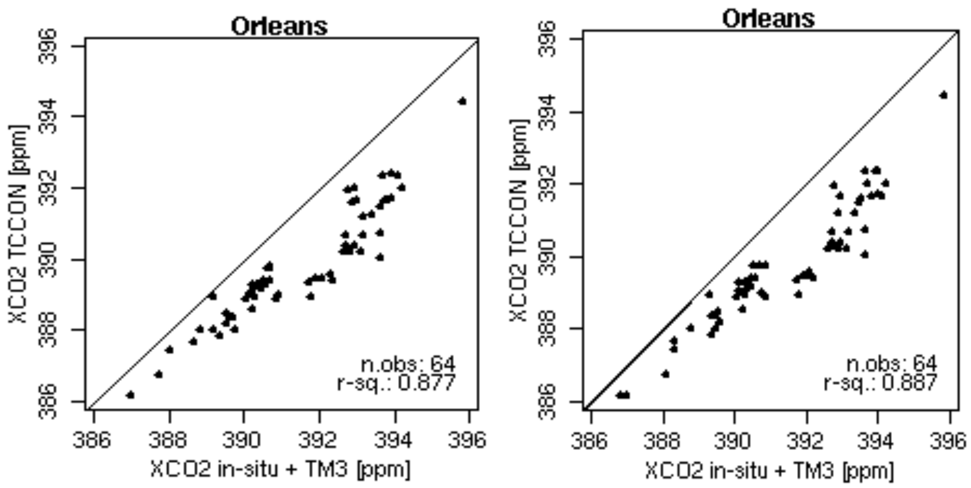

Figure 12: Comparison of TCCON XCO_2 with XCO_2 derived from the combination of tower-based in-situ CO_2. Left: Lidar observed mixing heights and remaining profile from TM3 analyzed fields . Right: same comparison but using MACC-derived mixing heights.

Replacing MACC-derived BLH by Lidar-observed BLH produced no obvious difference. However, the available data was very sparse with only 64 observations that had both tall-tower and TCCON measurements as well as BLH from the Lidar. The anomalies could not be calculated as the number of matching observations was even smaller: 56 for the synoptic anomalies and only 9 for the diurnal anomalies.

4 CONCLUSION

In general, the dry-air mole fractions retrieved by the different methods (TM3 model, synthetic model + tall-tower in-situ, TCCON) agreed within limits. The model-derived columns are likely biased high vs. TCCON during winter and also possibly during summer. One possible reason could be that the age of air in the stratosphere is too low in the TM3 model. This would lead to overestimated CO_2 values in the upper part of the column.

More surprising was the small difference between CO_2 profiles derived from model + in-situ observations vs. just modelled ones. The original expectation had been that stronger impacts would be found when using in-situ observations from the towers rather than TM3 model output. However, this was only found for Orleans but not for Bialystok where general agreement was lower.

While an extension to more sites and species, and further analysis of the error budget is required, these results constitute an important progress in the comparability of in situ vs column measurements of trace gases, with the final objective of harmonizing these two measurement networks.

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