Author comments on "On the diurnal, weekly, seasonal cycles and annual trends in atmospheric CO_2 at Mount Zugspitze, Germany during 1981–2016" *by* Ye Yuan et al.

Ye Yuan on behalf of all co-authors

Answers to **Anonymous Referee #1 (RC1)**

The referee comments are shown in black. The answers are shown in blue.

Authors: We would like to thank Anonymous Referee #1 for the efforts to review this manuscript and to provide very helpful comments and detailed remarks. All the referee's comments have been carefully examined and addressed in the revised manuscript as well as supplement.

Review of the manuscript: "On the diurnal, weekly, seasonal cycles and annual trends in atmospheric CO2 at Mount Zugspitze, Germany during 1981–2016" by Y.Yuan et al. (Atmos. Chem. Phys. Discuss., https://doi.org/10.5194/acp-2018-850)

The paper is describing the long term CO_2 monitoring program at Zugspitze, Germany. Actually the time series is a composite from three periods during which the sampling location, the method and instrument were different: ZPT (1981-1997), ZUG (1995-2001), and ZSF (2001-ongoing). Consequently a major issue to be addressed in this study is the consistency of the three datasets, in order to determine if they can be grouped in a single series and with what limitations. I think this part is not detailed enough. The three datasets are merged for analysis of different time scale variabilities, although several indicators show that they differ significantly. A scientist using the Zugspitze long term time series without consideration of the change in the sampling location could misinterpret the signal. For this reason I would recommend the authors to clarify the uncertainties associated to such a merging of the different dataset.

Authors: Thank you very much for pointing this out. We have now included a detailed discussion about the offset adjustment between ZPT and ZUG in the manuscript and supplement. Later on we have always made the analyses for each measurement location (ZPT, ZUG, and ZSF) separately. Throughout the manuscript we have pointed out that the results of atmospheric CO_2 measurements at Mount Zugspitze are a composite of three data sets at different locations and for different time periods, which cover an overall time length of 36 years. When using these data sets, caution is needed and it is always

recommended to discuss questions regarding specific researches with the data provider. For more detailed changes please see the following answers.

2.1. Measurement sites: I would suggest not using the term 'sites' to distinguish between the three sampling locations (ZPT, SUG, ZSF) at Zugspitze. It is a source of confusion here and there in the manuscript.

Authors: Thank you very much for the suggestion. We changed all the expressions "sites" related to ZPT, ZUG, and ZSF into "locations" throughout the manuscript.

Schneefernerhaus (ZPT, 47°25′ N, 10°59′ E, slightly below the summit): please give the elevation asl

Authors: Done.

'Information for the first and second time periods were mainly collected based on personal communication with corresponding staff and logbooks': at least it would be good to get information on the general setup of the system (dryer, calibration, and data selection…).

Authors: A general instrumental setup of the measurement system at ZPT and ZUG has been implemented in the Section 2.2 (Instrumental setup and data processing).

"…The CO_2 measurement at ZPT was continuously performed with different, consecutively used instrument models (i.e., the URAS-2, 2T, and 3G) of nondispersive infrared (NDIR) technique. The measured values were corrected by simultaneously measured air pressure with a hermetically sealed nitrogen-filled gas cuvette due to no flowing reference gas used. Two commercially available working standards (310 and 380 ppm of CO_2 in N_2) were used for calibration every day at different hours. The CO_2 concentration in this gas bottle was compared in short intervals with a reference standard provided by UBA which was adjusted to the Keeling standard reference scale.

At ZUG the sampling line consisted of a stainless steel tube with an inner core of borosilicate glass and a cylindrical stainless steel top cup against intake of precipitation. The inlet with the structure of a small mast ended approximately 4 m on the top of the laboratory building, which is situated on the Zugspitze summit platform (see Fig. 1b). Inside the laboratory a turbine with a fast real-time fine control ensured a constant sample inflow of 500 l/min of in-situ air. The borosilicate glass tube (about 10 cm diameter) continued inside the laboratory, providing a number of outlets from where the instruments could get the sample air for their own analyses. The measurement and calibration were performed with a URAS-3G device and an Ansyco mixing box. The mixing controller allowed automatic switching for up to four calibration gases and sampling air by a self-written calibration routine using Testpoint software. The linear two-point calibration enveloping the actual ambient values with low and high CO_2 concentrations was taken at every 25^{th} hour. Every six months the working standards were checked and re-adjusted, when required, to the standard reference scale by inter-comparison measurements with the station standards…"

Do you use the data already selected (according to time of the day or other criteria) from previous site managers?

Authors: No, the data we used in this study were quality validated without application of any pre-selection procedures. Only obvious outliers, due to such as malfunction or power failure, were left out as mentioned in Section 2.2. Therefore we added in the manuscript,

"…The CO_2 data from these measurement sites and from Mount Zugspitze locations were considered as validated data set (Level 2: calibrated, screened, artefacts and outliers removed), without any further data processing prior to the selection of representative data…"

2.3. Offset adjustment: The offset between the two sites (ZPT and ZUG) is huge with a large dispersion (5 to 6 ppm). A more detailed analysis of this offset, looking at its variation in time (and instrumental change), as a function of the atmospheric pressure, or CO2 concentration must be provided.

I support the hypothesis that the carrier gas effect can explain most of the differences between ZPT and ZUG, since it is well known that the CO2 concentration in air when using N2 mixtures as references, is under-estimated by few ppm. However, a discussion on this issue must be provided by the authors, with references to previous studies based on similar NDIR instruments (e.g. Pearman et al., Tellus, 1975; Griffith et al., Tellus, 1982). Is the observed differences compatible with what we can expect considering the literature, and the atmospheric pressure at this altitude site?

Authors: Thank you very much for the helpful literature. We have made a more detailed description and analysis for the offset adjustment now in both the manuscript and supplement. Please check the following text.

In manuscript:

"…However, for the three-year parallel CO_2 measurements at ZPT and ZUG (1995–1997), clear offsets of –5.8 ± 0.4 ppm ($CO_{2,\ ZPT}$ minus $CO_{2,\ ZUG}$, $1 \cdot SD$) were observed. The major reason for this bias is assumed to be the pressure-broadening effect in the used gas analyzers and the different gas mixtures used in the standards, CO_2/N_2 vs. CO_2/air, the so called "carrier gas correction (CGC)" (Bischof, 1975; Pearman and Garratt, 1975). It is known from previous studies that the measured CO_2 concentration, when using CO_2/N_2 mixtures as reference, is usually underestimated by several ppms for the URAS instruments, and such offsets vary from different types of analyzers (Pearman, 1977; Manning and Pohl; 1986). The carrier gas effect varies even between the same type of analyzer as well as with replacement of parts of the analyzer (Griffith et al., 1982; Kirk Thoning, personal communication, August 1, 2018). Due to lack of information and impossible on-site experiments with previous calibration standards, an offset adjustment to the CO_2 data set at ZPT was made for further analyses based on the offsets in data computed in the overlapping years instead of a physically derived correction. A single correction factor

$$G = 0.956 + 0.00017 \cdot C_{ZPT} \qquad (1)$$

was applied to the ZPT data while C_{ZPT} denotes the CO_2 concentrations at ZPT. Because of the same calibration mixtures, an additional adjustment was applied to the CO_2 concentrations at WNK by calculating the CO_2 differences between ZPT and

WNK. A detailed description on the offset adjustment of CGC with potential errors is given in the supplement. Two similar CGCs by Manning and Pohl (1986) at Baring Head, New Zealand and Cundari et al. (1990) at Mt. Cimone, Italy, were comparable in magnitude to our offset adjustment…"

In supplement:

2. Offset adjustment

2.1. Offset adjustment background

From the observed data for the three-year parallel CO_2 measurements at ZPT and ZUG (1995–1997) we obtain an offset of –5.8 ± 0.4 ppm ($CO_{2,\,ZPT}$ minus $CO_{2,\,ZUG}$, $1 \cdot SD$). In the present situation, on-site corrections based on different calibration standards and different types of analysers are no longer possible. Therefore instead of a laboratory data based correction of this offset, we performed an offset adjustment, which was based on the historical time series. Above all, depending on the existing information, we have to make the assumption that none of the following effects have been corrected beforehand at ZPT but at ZUG.

As mentioned in the paper, it is assumed that such a large offset (several ppm) is mostly influenced by the so-called "carrier gas effect" on the infrared gas analysis investigated by Bischof (1975) and Pearman and Garratt (1975). There a considerable deviation was detected due to the pressure broadening effects on the different types of used gas analyser, and more importantly to the different carrier gases used in the standards, i.e. CO_2/N_2 mixtures vs. CO_2/air mixtures. In Table S2, it is shown that between ZPT and ZUG during 1995–1997, the same type of analysers (URAS 3G, Hartmann & Braun) were used, but however the calibration gases were different (CO_2/N_2 for ZPT and CO_2/natural air for ZUG). Experiments implied that the CO_2 concentration in air when using CO_2/N_2 mixtures as references is usually underestimated by several ppms for the URAS instruments. On the other hand, the measurement of CO_2 concentration in air is not affected if CO_2/air mixtures were used as references. From Pearman (1977), we learnt that the potential carrier gas error could range from –4.9 to +3.8 ppm (8.7 ppm in absolute difference) depending on different analysers (Bischof, 1975; Pearman, 1977). Griffith (1982) showed that this can vary even between analysers of the same type.

Table S1: Detailed description of atmospheric CO_2 measurement techniques (NDIR = Nondispersive infrared, GC = Gas chromatography, and CRDS = Cavity ring-down spectroscopy).

ID	Time period	Instrument (Analytical method)	Scale	Calibration gas
ZPT	1981–1997	1981–1984: Hartmann & Braun URAS 2 (NDIR) 1985–1988: Hartmann & Braun URAS 2T (NDIR) 1989–1997: Hartmann & Braun URAS 3G (NDIR)	WMO X74 scale	CO_2 in N_2
ZUG	1995–2001	Hartmann & Braun URAS 3G (NDIR)	WMO X85 scale	CO_2 in natural air
ZSF	2001–2016	2001–2016: Hewlett Packard Modified HP 6890 Chem. station (GC) 2012–2013: Picarro EnviroSense 3000i (CRDS)	WMO X2007 scale	CO_2 in natural air
WNK	1981–1996	Hartmann & Braun URAS 2T (NDIR)	WMO X74 scale	CO_2 in N_2

Pearman (1977) also mentioned that both the sign and magnitude of the carrier gas error depend on not only the configuration and model of analyser used, but also the ambient pressure at which measurements are made, i.e. the station altitude. With an altitude difference of around 1.6 km, a difference in carrier gas effect of ~0.6 ppm was found when measurements were made with a URAS 2 (Pearman and Garratt, 1975). At Mount Zugspitze, the altitude difference between ZPT and ZUG is approximately 250 m, and thus the carrier effect dependence on the ambient pressure is rather limited.

Another potential factor is the drying problem due to the varying water content as described in Reiter et al. (1986). By comparing an URAS 2T with a URAS 3G at another measurement station in Garmisch-Partenkirchen (GAP), the humidity-induced error ranged from the extreme conditions in summer (at most 6 ppm), to 2 ppm in winter. Pearman (1975) also addressed this problem as non-dispersive infrared gas analysers were influenced by water vapour in the air sample. The subsequent measurement must be corrected by multiplying the indicated concentration by $(1 + 1.61 * r)^{-1}$, where r is the water vapour mass mixing ratio of the undried air. However, such error indicated that the measured CO_2 concentration would be overestimated when not corrected. Moreover, this error also decreases with altitude and will be less than the resolution of the NDIR analysers (approximately ±0.2 ppm) above about 8 km a.s.l. Regarding that the absolute water content for mountain stations is, on average, very low (for example at ZSF, the relative humidity in sampling air ranges between 2–10% in winter and approximately 27–32% in summer at 20°C), such an effect of drying the air sample prior to analysis was assumed to be minor for Mount Zugspitze.

2.2. Offset adjustment at ZPT

In order to make the offset adjustment, we follow the approach from Griffith (1982) and Griffith et al. (1982), together with comparing similar carrier gas correction cases done by Manning and Pohl (1986b) and Cundari et al. (1990). The general assumption is that the carrier gas correction (CGC) term is proportional to CO_2 concentration (Griffith, 1982; Manning and Pohl, 1986a). Carrier gas effects were determined experimentally by comparing analyser values (apparent CO_2 concentration C_a) with true (mano-metrically determined) CO_2 concentration (true CO_2 concentration C_t). Two terms were used here as the carrier gas shift (Δ) and the correction factor (G).

$$\Delta = C_a - C_t \quad (1)$$

$$G = C_t / C_a \quad (2)$$

In our case, given that CO_2 measurements between ZUG and ZSF show a comparable result in 2001, and the altitude difference between ZSF and ZPT is only about 70 m a.s.l., we consider the CO_2 measurements at ZUG to be the true value ($C_{ZUG,t}$) and the CO_2 measurements at ZPT to be the apparent value ($C_{ZPT,a}$). Thus the offset can be expressed as (see Fig. S2a),

$$\Delta = C_{ZPT,a} - C_{ZUG,t} \quad (3)$$

and hence the correction factor can be expressed as (see Fig. S2b),

$$G = C_{ZUG,t}/C_{ZPT,a}. \quad (4)$$

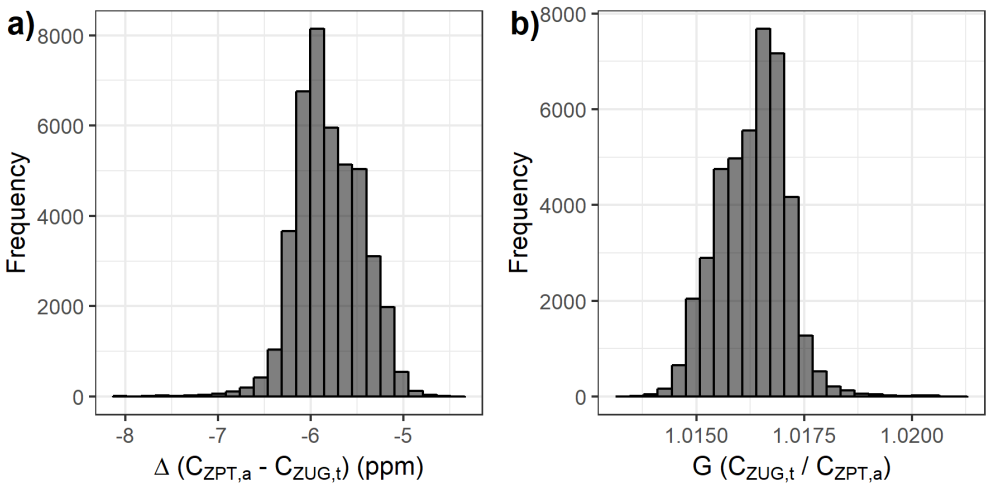

Figure S2: a) Histogram for the offsets (Δ) between CO_2 measurements at ZPT and ZUG for the period of 1995–1997. b) Histogram of the correction factor (G) between CO_2 measurements at ZPT and ZUG for the period of 1995–1997.

We then plotted the computed correction factors G with the apparent concentration at ZPT ($C_{ZPT,a}$) throughout the three years (1995–1997) in Fig. S3. A linear relationship can be observed but for a certain interval of the data a clear shift is noticed. Then we tried to divide the time blocks and took a closer look at when or how this shift takes place. We found out that this shift happened from November to December 1995, possibly due to instrumental setup changes. Figure S4 showed the time blocks before, during, and after. Nevertheless, by fitting linear regression nearly identical regression lines were produced for all three time blocks. At the CO_2 concentration of 360 ppm, the correction factors for the three time blocks were computed as 1.01728, 1.01684, and 1.0172 respectively, in terms of the adjusted values of 366.2208, 366.0624, 366.192 ppm with a span of ±0.08 ppm. Within the interval from 340 ppm to 370 ppm of atmospheric CO_2 concentrations, the same calculation applied shows an error range in the adjusted values from ±0.06 to ±0.09 ppm.

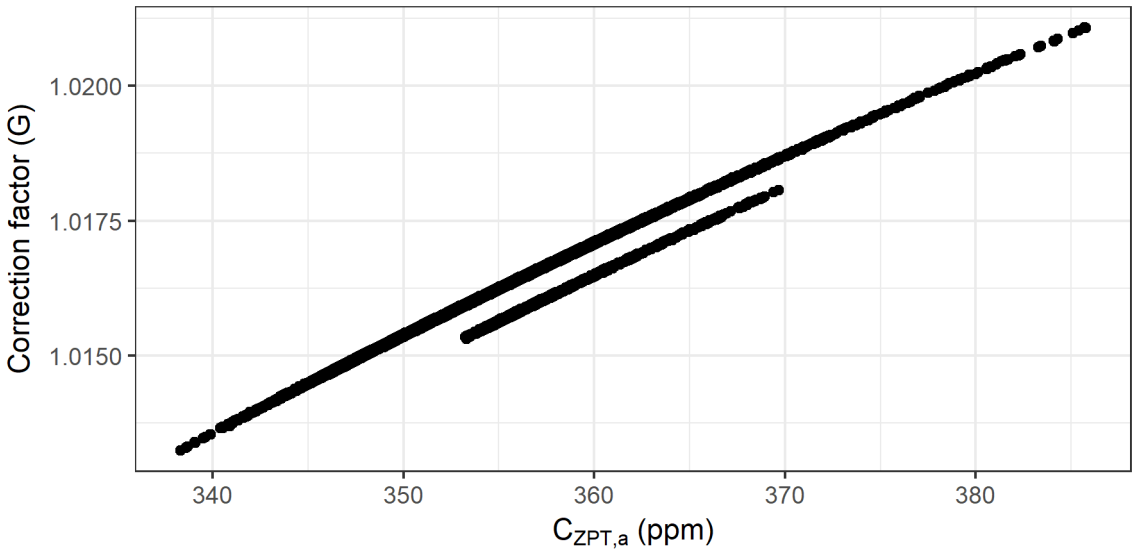

Figure S3: Computed correction factor G against CO_2 concentrations at ZPT from 1995 to 1997.

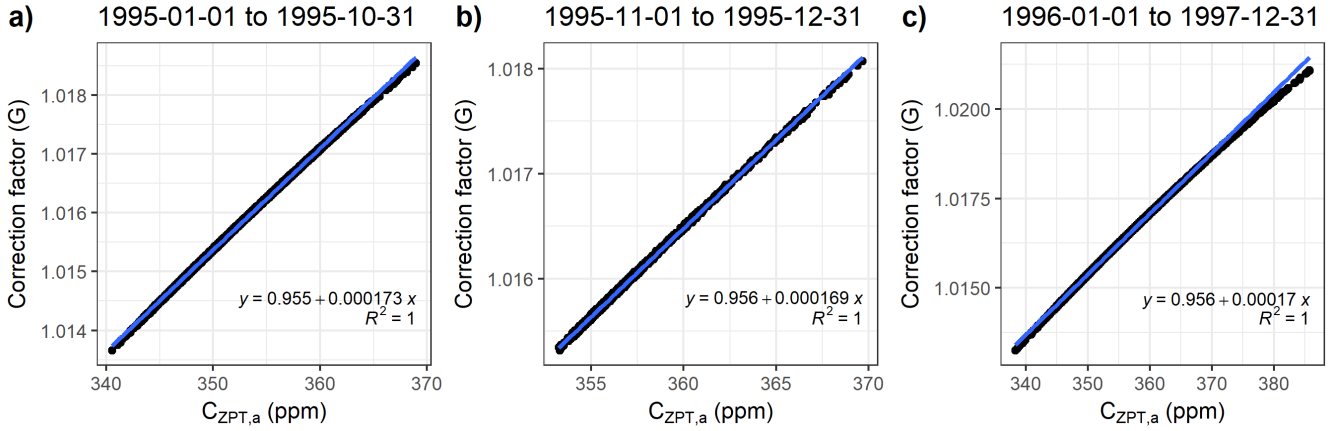

Figure S4: Computed correction factor G against CO_2 concentrations at ZPT from 1995 to 1997 with three separate time blocks.

Therefore, for the shifted time block (1995-11-01 to 1995-12-31), we used the correction factors by the linear regression function in Fig. S4b. Since the rest of the time blocks showed nearly identical results, we combined the data together and made a new linear regression. Based on this regression function, we made the following offset adjustment for all the remaining CO_2 data sets at ZPT (1981–1997) except for the two months in 1995, as shown below

$$G = 0.956 + 0.00017 \cdot C_{ZPT,a}. \quad (5)$$

And the adjusted CO_2 concentrations at ZPT can be expressed as

$$C_{ZPT,t} = C_{ZPT,a} \cdot G = C_{ZPT,a} \cdot \left(0.956 + 0.00017 \cdot C_{ZPT,a}\right). \quad (6)$$

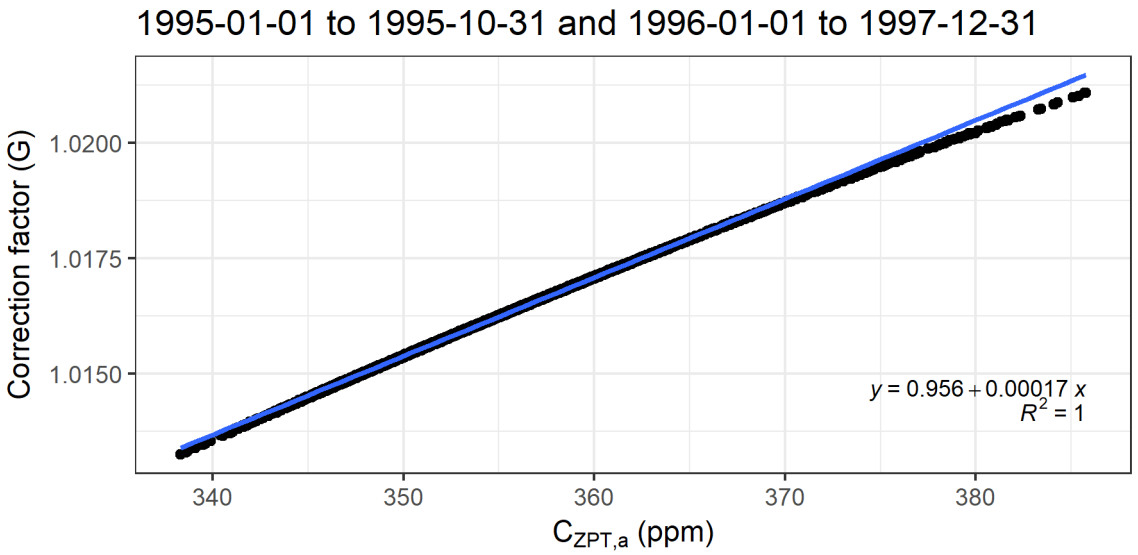

Figure S5: Computed correction factor *G* against CO_2 concentrations at ZPT from two separate time blocks, used for offset adjustment on the CO_2 data set at ZPT.

The reason we chose a single correction factor for most of the years is that, from the given comparison of the three separate time blocks, the error is small (less than 0.1 ppm). Therefore it is assumed that with different instruments used throughout the measurement periods the offsets remain small and hence relatively stable. Figure S5 also showed that the points were slightly off the regression line at both the head and tail even with $R^2 = 1$. This leads to errors of up to 0.2 ppm for a range of 338.32 to 385.69 ppm (CO_2 minimum and maximum at ZPT for this period), which agrees well with Griffith et al. (1982) as same errors of up to 0.2 ppm were detected for a range of 200 to 450 ppm. As a result, the offset adjustment of single correction factor is considered to be adequate.

In two similar cases, Manning and Pohl (1986b) showed the CGC at a concentration of 340 ppm for the URAS-2T analyser varied from 5.5 ppm to 3.2 ppm. With our correction factor function at the concentration of 340 ppm, the CGC turns out to be 4.7 ppm, which is in a good agreement. From another study by Cundari et al. (1990), by a least-square linear interpolation the experimentally determined means of the ratios were expressed by the following equation

$$\bar{G} = 1.0008 + 2.51 \cdot 10^{-5} \cdot C_a. \qquad (7)$$

Given the described range of C_a approximately from 320 to 360 ppm, the ratio varied from 1.008832 to 1.009836 which in terms of CGC the values changed 2.8 to 3.5 ppm. With the same described range, the CGC based on our regression function results in the values between 3.3 and 6.2 ppm.

2.3. Offset adjustment at WNK

Due to lack of information and no available comparable additional measurements at nearby locations, we decided to make a more general offset adjustment on CO_2 data at WNK based on the adjusted CO_2 data at ZPT because the same CO_2/N_2 mixtures were used for calibration (see Table S1). The time period of CO_2 measurements at WNK used in this study is 1981–1996, which is completely covered by CO_2 measurements at ZPT. We assume that the differences in CO_2 concentrations remain similarly before and after the offset adjustment, which means

$$C_{WNK,a} - C_{ZPT,a} \approx C_{WNK,t} - C_{ZPT,t}. \quad (8)$$

Therefore, the adjusted CO_2 concentrations at WNK can be expressed as

$$C_{WNK,t} = C_{ZPT,t} + \left(C_{WNK,a} - C_{ZPT,a}\right). \quad (9)$$

Finally the offset adjustment at WNK was done by calculating the differences in CO_2 concentrations between WNK and ZPT raw data and then adding it to the adjusted CO_2 concentrations at ZPT to compute the adjusted CO_2 concentrations at WNK.

2.4 Offset adjustment error estimation (ZPT to ZUG)

At the end, the maximum possible error should be estimated. Based on literature review, several additional factors which may contribute to it apart from carrier gas effect, pressure effect, and drying problem (varying water content) were listed as mentioned above.

- Absolute limit error on every single G ratio: 0.4 ppm (Cundari et al., 1990)
    - Station relative accuracy: ± 0.2 ppm (Pearman, 1975)
- Temperature effects: URAS analyzers are thermostated and small temperature variations, as are likely to occur, should not cause noticeable errors and thus can be neglected (Griffith et al., 1982).
- Leaking detectors: 0.4 ppm (+ 0.4 ppm) for URAS analyzers with different leaking scenarios (Griffith et al., 1982)
    - We assume that according to the applied quality standard from the former IFU (Fraunhofer Institute for Atmospheric Environmental Research, today KIT/IFU) the analyzers did not have a systematic leaking.
    - Further it is assumed, that the measurements did not have a drift in the data, because of continuous quality assurance for the former IFU.

Based on the given information about the measurements, we did a practically best possible description of obviously existing errors in the values. Please always keep in mind that this is an attempt and approach to make proper use of these historical data with given errors. Different time period, different types of analysers (also the same type), different used reference gases, or any potential replacement on the instruments and artefacts would introduce more errors to the offset adjustment. Caution should always be taken when using this combined data set. We would recommend contacting the data provider for more detailed discussion, whenever a detailed analysis requires reliable information.

I understand that you have not applied the offset correction (-0.11ppm) between ZUG and ZSF. Please make it clear.

Authors: Done. We added, "…Therefore, no adjustments regarding this offset were applied to the data sets…"

2.4. ADVS data selection: "The percentages of ADVS-selected data are … 13.5% for Zugspitze": have you merged all three Zugspitze stations together in this analysis? Does it mean there is none significant differences between them?

Authors: For the ADVS data selection, the three measurement locations at Mount Zugspitze were processed separately. Previously the results of selected percentage were computed after combining the three data sets together. Now we calculated the selected percentages separately as well as shown in the plot (see Fig. 2a). There are significant differences in the selected percentages at a 95% confidence interval among the three measurement locations. From the selected results, we can see different percentages of selected data at the three measurement locations, i.e. ZPT (9.9%) > ZSF (13.6%) > ZUG (19.5%). In that way we can detect the highest data variability at the pedestrian tunnel (ZPT) and the lowest variability at Zugspitze Summit (ZUG).

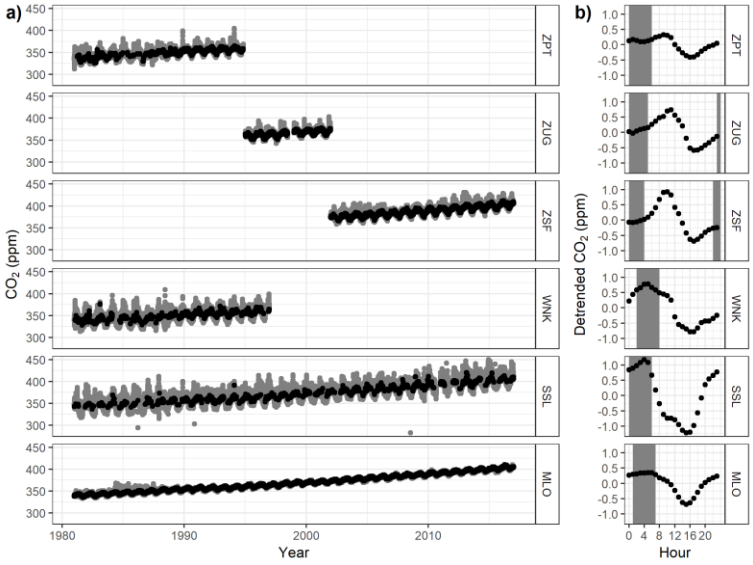

Figure 2: a) Time series plot of 30-min averaged CO_2 concentrations measured at Mount Zugspitze (ZPT, ZUG, and ZSF) and Wank (WNK), and hourly averaged CO_2 concentrations measured at Schauinsland (SSL) and Mauna Loa (MLO) with ADVS-selected results. b) Detrended mean diurnal cycles with starting time windows (in grey) for ADVS data selection.

Could you provide some statistics of the hours which are selected at Zugspitze as representative of the background according to ADVS method?

Authors: Yes, we added a graph of the resulting starting time window in Fig. 2b for each measurement site/location. A grey tone scale shows the frequency of ADVS-selected CO_2 data per hour in the total number of CO_2 data in Fig. 3. And a general discussion based on the diurnal variation is given in Sect 3.1, as the following.

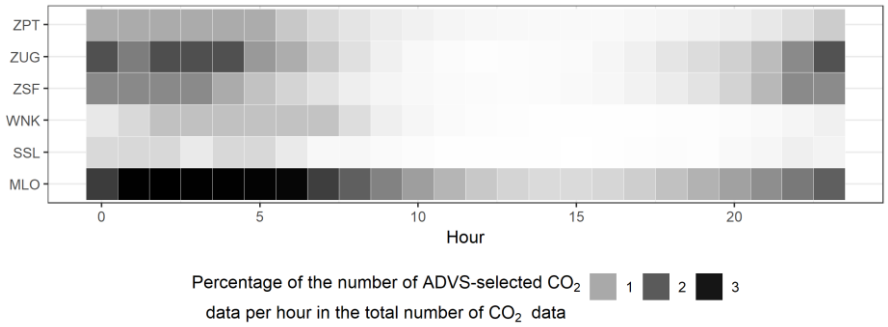

Figure 3: Frequency of the percentages of the number of ADVS-selected CO_2 data for each hour (0 to 23) in the total number of CO_2 data. In the shown greyscale grey means 1%, 2% and black means 3% of the data.

"…The resulting ADVS-selected CO_2 data showed a clear linkage of the percentage of selected data and the altitude of the measurement site. Among the continental stations, the percentage increased with altitude. Lower percentage indicates higher data variability due to lower elevation and proximity to local sources and sinks. At Schauinsland, the percentage of CO_2 data by the ADVS selection was 6.3% while the percentages at Mount Zugspitze reached 9.9% (ZPT), 19.5% (ZUG), and 13.6% (ZSF), respectively. A moderate percentage of 6.3% was also derived at Mount Wank. However, regarding the elevated mountain station Mauna Loa on the island of Hawaii, a much higher percentage (40.0%) of CO_2 data was selected by ADVS as representative of its background concentration mainly due to the very limited nearby anthropogenic sources as well as mostly clean, well-mixed air arriving there. A similar result for an island mountain station can be found in Yuan et al. (2018) where a percentage of 36.2% was computed for the CO_2 measurements at the station Izaña on Tenerife Island (28°19′ N, 16°30′ E, 2373 m a.s.l.). This can also be explained by the detrended mean diurnal cycles shown in Fig. 2(b) and Fig. 3. The mean diurnal cycle at MLO only exhibits a clear trough during daytime, especially starting from 12:00h local time (LT), which is believed to be influenced by the vegetation activity (photosynthesis) in the surroundings. The same effect can be seen at WNK and SSL, but with larger magnitudes and earlier occurrences of the minima because of their lower locations closer to CO_2 sinks. In contrast, at these two sites the CO_2 maxima in the diurnal cycles were not as clearly noticeable as at Mount Zugspitze due to anthropogenic sources and high biogenic respiration. At the three locations of Mount Zugspitze, the CO_2 peaks in the mean diurnal cycles are driven by the late-morning convective upslope wind, which was relatively obvious at both ZUG and ZSF. However, from the perspective of data selection, a significantly higher percentage of CO_2 data was selected at ZSF compared with ZPT although there is only a small difference in altitude of around only 70 m. This proves that ZSF is capable to capture more background conditions than ZPT during the day. Nevertheless, based on the starting time window computed for ADVS selection, we found that, in general, most stations exhibited similar starting time windows beginning around midnight and the ADVS data selection was applied systematically by including more data around these hours (see Fig. 3), which confirmed our assumption of background conditions during midnight for the ADVS data selection (Yuan et al., 2018)…"

2.5. STL decomposition Missing monthly values were substituted by spline interpolation: do you allow an interpolation of large data gaps like several consecutive months?

Authors: No, such large data gaps of several consecutive months are not allowed. And that is the reason why we previously decided to apply STL decomposition only on the original CO_2 data sets without ADVS data selection to evaluate the trend and seasonality. Besides, for the global trend data sets applied by the same STL decomposition technique, there are only monthly values available which cannot be selected by ADVS. Regarding the original CO_2 data sets, there is only one such large data gap for consecutive six months, which occurred at ZUG from July to December of 1998. Thus we performed the STL decomposition separately before and after this time period.

For improvement, we decided now to also apply STL decomposition to the ADVS-selected data at stations at Mount Zugspitze and Mauna Loa, as there are no large data gaps in the monthly averages from ADVS-selected data at these sites/locations. These results are implemented and discussed throughout the manuscript.

"…especially for measurement sites at lower elevations": I am confused about which sites you are referring to. Low altitude sampling locations at Zugspitze, or other sites like Schauinsland? Can you be more specific about the data gaps at stations, since it would make much more sense to use background data (after ADVS selection) for the seasonal and trend analysis, especially when comparing at other large scale time series.

Authors: More descriptions have been added in the text and also mentioned in the previous answer. Here the measurement sites at lower elevations refer to WNK and SSL. For a detailed illustration on each component of STL decomposition, we now included all the decomposed plots in Supplement S3.

3.1. Trend and seasonality "Only the mean annual growth rate between 1995 and 2001 at the ZUG site is much lower than the other sites due to missing values in 1998": Not clear for me why the 6 months data gap in summer 1998 decreases so much the total trend over the period 1995 to 2001. Please clarify.

Authors: Sorry for the confusion. What we want to point out is that because of the data gap in 1998 at ZUG, the annual growth rates of 1998 and 1999 are not accounted for in the mean annual growth rate calculation. However, for all of the other measurement sites, a clear anomalous peak in CO_2 annual growth rate is shown which can be attributed to a strong El Niño event. Therefore, we have rephrased this paragraph as the following.

"…This can be explained by the missing monthly values in 1998 and thus in turn the annual growth rates of 1998 and 1999 were left out for the average. However, the annual growth rates of these two years reached anomalous peaks at most sites (see details later in Sect. 3.6)…"

"Amplitudes of 15.44 and 14.89 ppm": For most signals I would suggest rounding the values to one decimal place.

Authors: Thank you very much for your suggestion. We have rounded all the values across the manuscript and rewrote the content accordingly.

The comparison of the seasonal cycles would be much more meaningful with background selected data. By the way do you use also all data (without selection) at SSL, WNK and MLO sites, or do you use the data selected by the station's managers at those sites? Please clarify. It could be interesting to see if the ZSF site remains more influenced by the air from the valleys, compared to ZPT and ZUG, once you have selected the nighttime values at all sites.

Authors: As mentioned above, we have now included the ADVS-selected data sets for the comparison of the seasonal cycles at Mount Zugspitze and Mauna Loa and similar results were found.

For sites SSL and WNK, all data were used for the analyses. There, no pre data selection routines have been performed. Therefore we added at the end of Sect. 2.2,

"…The CO_2 data from these measurement sites and from Mount Zugspitze locations were considered as validated data set (Level 2: calibrated, screened, artefacts and outliers removed), without any further data processing prior to the selection of representative data…"

Regarding the comparison among ZSF, ZPT, and ZUG, the results of seasonal cycles are similar for the ADVS-selected data sets, that for ZSF clearly higher CO_2 levels were observed from January to March and lower CO_2 levels were observed from July to September (see Fig. 7).

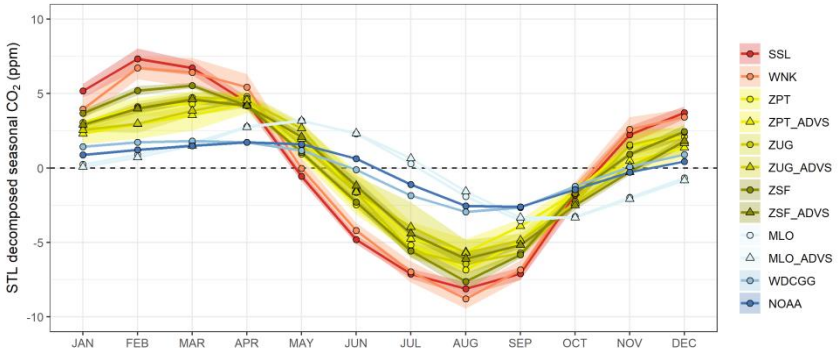

Figure 6: Mean CO_2 seasonal cycles from the STL seasonal component at each measurement site or location. Uncertainties at a 95% confidence interval are shown by the shaded areas with corresponding color.

"there are slight differences in seasonal amplitudes (ZPT: 10.86 ppm; ZUG: 11.14 ppm; ZSF: 13.09 ppm) among the three sites": I would not call a 2 ppm signal a slight difference ! A major signal to look at for such long term time series in North Hemisphere would be a possible trend in the amplitude of the seasonal cycle which could indicate a trend in the way the biosphere is interacting with atmospheric CO2. Graven et al., 2013 described for example increasing trends of the seasonal CO2 amplitude of 0.32 % per year at Mauna Loa and 0.60 % per year at Point Barrow. Considering a mean amplitude of about 12 ppm you could expect a trend of 1.4 to 2.5 ppm over the 36 years period of measurement at Zugspitze (assuming the MLO and BRW trends).

Authors: Thank you very much for the correction and information. We leave out the "slight" in the sentence. And with the new offset adjustment, the results are,

"…Despite the close proximity, there are differences in their seasonal amplitudes (ZPT: 11.9 ± 1.2 ppm; ZUG: 11.2 ± 1.0 ppm; ZSF: 13.3 ± 0.7 ppm). Good agreement is shown between CO_2 seasonal cycles from April to June and from October to December. However, significantly higher levels of CO_2 were evident at ZSF from January to March as well as lower levels from July to September. After data selection with lower seasonal amplitudes of 10.3 ± 1.3 ppm (ZPT_ADVS), 10.3 ± 1.2 ppm (ZUG_ADVS), and 10.9 ± 0.6 ppm (ZSF_ADVS), similar differences of the CO_2 levels in the seasonal cycles could be observed…"

Figure 3: the significant differences you show on figure 3b with the 3 sampling locations should prevent you from mixing those three dataset together as you do in figure 3a.

Authors: Thank you for the insight. As mentioned above, we have separated the three locations in all figures.

3.2. Inter-annual variations Abnormal high percentage at Zugspitze in 2000: I do not understand the sentence on line 5/6 suggesting that a careful and intensive selection was performed in 2000. Is the selection process different from the other years?

Authors: Sorry for the confusion. The original CO_2 data at ZUG was provided by the previous station manager Dr. H-E. Scheel, IFU. By direct cooperation, we learnt at that time that due to temporary systematic local effects of inflow of in-situ air to the sampling unit the CO_2 data at ZUG in 2000 had to be intensively selected by the operator. However the CO_2 data was only available in the format after this intensive selection so that such abnormal high percentage was derived.

Again, due to the differences between the three sampling locations (especially ZSF which is more influenced by air uplifted from the valleys) I think you should differentiate them in figure 4.

Authors: Done.

3.3. Weekly periodicity I would suggest to discuss short-term variabilities (weeks and daily) before trend and inter-annual variations.

Authors: Thank you for the suggestion. We have changed the order of the subsections in the results and discussion. Now we follow that,

- Sect. 3.1 ADVS selection and diurnal variation
- Sect. 3.2 Weekly periodicity
- Sect. 3.3 Case study on atmospheric CO, NO, and passenger numbers at Zugspitze
- Sect. 3.4 Trend
- Sect. 3.5 Seasonality

- Sect. 3.6 Inter-annual variation

I do not see the interest of comparing the weekly variations at Zugspitze to the one observed at Mauna Loa.

Authors: We decided to keep the comparison of the weekly periodicity between Mount Zugspitze and Mauna Loa. The reason is that this method of calculating the MSR values for evaluating the weekly cycle was developed by using the Mauna Loa CO_2 data (Cerveny and Coakley, 2002). The results show different weekly characteristics between ZSF and MLO, but not for the previous time periods with ZPT and ZUG.

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