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Interactive Comment

Interactive comment on "Temporal variations in CO_2 and CO at Ahmedabad in western India" *by* N. Chandra et al.

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General: We are very much grateful to the referee for appreciating our work and giving very helpful suggestions and comments, which have significantly improved the manuscript. We have revised the manuscript by carefully taking into account all the comments point by point. Text in red and blue colour show the questions and answers, respectively.

Anonymous Referee #1

This paper presents a year of data on CO and CO2 concentrations from a site in Ahmedabad. High quality concentration data from urban areas in general are sparse, and such data from the large urban areas in rapidly developing regions are especially

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limited. These observations can contribute to understanding emission patterns in a poorly studied region that is critically important to the global carbon budget. The experimental methods are excellent and include decent calibration scheme. The text provides a good summary of the methods and defines precision and accuracy. However, the discussion needs to be more focused and strive to present a consistent set of key findings. As noted in detailed comments, some observed variations in concentrations may not contribute to interpreting emissions patterns. The results will be more convincing by focusing on the key aspects of the data. It is important to distinguish between patterns with information about atmospheric dynamics (vertical mixing and transport) and patterns that have information about emission sources.

Comments and suggestions for revised analysis.

Page: 32200: With respect to the evolution of CO2 during night time. Even in cold regions there soils approach 0C respiration continues throughout the night. At this site I don't think you can attribute lack of increasing CO2 during night in some seasons to respiration being dormant. There is certainly no evidence included in the text for this. In this site I would only expect respiration to be suppressed by very dry soils, so it could be a reason in the spring, but temperatures are probably not cold enough to suppress respiration. You don't show any data for night time winds. Differences in depth and strength of the nocturnal inversion and whether winds persist at night are factors that would impact whether trace gases accumulate at the surface during night. In subsequent section you show that night time concentrations of CO decline continuously in the winter and spring season, which indicates that there is enough vertical mixing of low CO air from above that once the CO source is turned off its concentration drops. Thus, the constant CO2 at night is evidence of a continued source in order to offset dilution by mixing of low CO2 air from aloft. The dynamics of CO2 is not just the depth of mixing. You can note that because there is active CO2 uptake during seasons when vegetation is active the entire mixed layer is depleted during daytime and when residual layer mixes to the surface in morning, low-CO2 air is mixed down.

Response: We are very much grateful for these wonderful explanation and suggestions. We have included above suggestions in the explanation of the main text as well as we have also revised respective sections, as per suggestions of the second referee. The revised text is given below.

Diurnal variation of CO2 :

"Figure 5a shows the mean diurnal cycles of atmospheric CO2 and associated 1-σ standard deviation (shaded region) during all the four seasons. All times are in Indian Standard Time (IST), which is 5.5 hrs ahead of the Universal Time (UT). Noticeable differences are observed in the diurnal cycle of CO2 from season to season. In general, maximum concentration has been observed during morning (0700-0800 hrs) and evening (1800-2000 hrs) hours, when the ABL is shallow, traffic is dense and vegetation respiration dominant due to absence of photosynthesis activity. The minimum of the cycles occurred in the afternoon hours (1400-1600 hrs), when the PBL is deepest and well mixed as well as when the vegetation photosynthesis is active. There are many interesting features in the period of 0000-0800 hrs. CO2 concentrations start decreasing from 0000 to 0300 hrs and increases slightly afterwards till 0600-0700 hrs during summer and autumn. Respiration of CO2 from the vegetation is mostly responsible for this night time increase. During winter and spring seasons CO2 levels are observed constant during night hours and small increase is observed only from 0600 to 0800 hrs during the winter season. While in contrary to this, subsequent section shows a continuous decline in the night time concentrations of main anthropogenic tracer CO, which indicates that there is enough vertical mixing of low CO air from above once CO source is turned off, its concentration drops. Hence, constant levels of CO2 at night hours during these seasons give the evidence of a continued but weak source (such as respiration) in order to offset dilution of mixing of low CO2 air from aloft. Dry soil conditions could be one of the possible cause for weak respirations. Further, distinct timings have been observed in the morning peak of CO2 during different sea-

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sons. It is mostly related to the sunrise time, which decides the evolution time of PBL height and beginning of vegetation photosynthesis. The sunrise occur at 0555-0620 hrs, 0620-0700 hrs, 0700-0723 hrs and 0720-0554 hrs during summer, autumn, winter and spring respectively. During spring and summer, rush hour starts after sunrise, so the vehicular emissions occur when the PBL is already high and photosynthetic activity has begun. The CO_2 concentration is observed lowest in the morning during the summer season as compared to other seasons. This is because CO_2 uptake by active vegetation deplete the entire mixed layer during day time and when residual layer mixes to the surface in the morning, low-CO_2 air is mixed down. In winter and autumn, rush hour starts parallel with the sunrise, so the emissions occur when the PBL is low and concentration build up is much stronger in these seasons than in spring and summer seasons".

We have also plotted the diurnal variations of mean wind speed, which shows relatively calm winds in the autumn, winter and spring seasons. This information is mentioned in the text, when we discussed the night time ratio of CO and CO_2. The wind data for monsoon period is not available due to break down of wind sensor in the high thunderstorm. The Fig.1 is given for your reference only.

Page: 32201: This paragraph about comparison to a model ought to come later as discussion and not be in the results. Also, keep in mind that the magnitude of concentration variation is not directly proportional to the magnitude of a flux. In a simple sense the amplitude of concentration changes are proportional to flux divided by mixed layer depth and strength of vertical mixing. In order to use the observed concentrations to evaluate the validity of modelled CO_2 fluxes you need to consider what the influence region for the concentration is and convert the observations and model to comparable units. Either combine concentration data and typical mixing depth evolution to estimate a change in column density, or merge the CASA fluxes with a transport model to predict concentrations. The claim that model and observations are inconsistent is not convincing. The greatest magnitude of net daytime uptake and difference between

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CASA fluxes in day and night is in September through November, consistent with the peaks in amplitude of mixing ratio diel cycle (day/night difference of CO2 concentration increases from 20 ppm in August to 50 ppm in October). So I don't see where the observations suggest productivity is higher in August than Sept-October.

Response: Thank you very much for your kind suggestion. Now, we have moved this figure in Section 4.7.1. It is clear from Figure 6 that the CO2 flux diurnal cycle as modelled by CASA shows minimum day-night variation amplitude during the summer monsoon time (Jun-July-Aug). Given that the biosphere over Ahmedabad is water stressed for all other three seasons (except the summer monsoon time, Fig. 1A3), the behaviour of CASA model simulated diurnal variation is not in line with biological capacity of the plants to assimilate atmospheric CO2.

Due this underestimation of CO2 uptake in the summer monsoon season, we also find very large underestimation of the seasonal trough by ACTM in comparison with observations (Fig. 11). The variations in transport, PBL ventilation and horizontal winds are included in the ACTM simulation, therefore we do include "proportional to flux divided by mixed layer depth and strength of vertical mixing" in our model results.

For these reasons, we propose that summer time underestimation of CO2 flux diurnal simulation by CASA is a clearly convincing case.

Page: 32202: The statement here on pg32302, line 26 about respiration contributing to CO2 is inconsistent with the previous section suggesting that respiration was dormant.

Response: According the first suggestion, we have modified both explanations for CO2 and CO. In CO2 section, we have added following explanations.

"CO2 concentrations start decreasing from 0000 to 0300 hrs and increases slightly afterwards till 0600-0700 hrs during summer and autumn. Respiration of CO2 from the vegetation is mostly responsible for this night time increase. During winter and spring seasons CO2 levels are observed constant during night hours and small increase is

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observed only from 0600 to 0800 hrs during the winter season. While in contrary to this, subsequent section shows a continuous decline in the night time concentrations of main anthropogenic tracer CO, which indicates that there is enough vertical mixing of low CO air from above that once CO source is turned off, its concentration drops. Hence, constant levels of CO2 at night hours during these seasons give the evidence of a continued but weak source (such as respiration) in order to offset dilution of mixing of low CO2 air from aloft. Dry soil conditions could be one of the possible causes for weak respirations".

For CO section, we have modified the statement on pg32302, line 26. "The third noticeable difference is that the CO levels decrease very fast after evening rush hours in all the seasons while this feature is not observed in case of CO2, since respiration during night hours contributes to the levels of CO2. The continuous drop of night time concentrations of CO indicates that there is enough vertical mixing of low CO air from above once the CO source is turned off".

Page: 32204: The regression slopes for CO: CO2 are not credible estimates of the emission ratio. The difference between actual background CO2 and the assumed constant value that is used to compute excess is correlated with time of day and thus with CO, so the slope of CO: CO2 will be corrupted I do notice that the upper edge in all the figures appears to have a similar slope. That edge represents the air that is most strongly influenced by CO emission sources. Although I think it would be better to split up the data into groups that actually show a decent correlation, if you want to stick with the overall regression those lines should be shown on the figure and for comparison include some lines that show the slopes for a few representative emission sources.

Response: Thank you very much for raising this important point. As per the suggestion, we have removed the old diagram and added a new diagram (Fig. 2) in the main text, which shows the correlation at different time windows during different seasons and including the range of emission ratios of different sources from the available literature. We have also included the Table S1 (given in the supplementary) in the main text, which

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gives the summary of the new diagram. According to diagram, we have significantly modified the text of the whole section.

Note that in previous section examining diel cycles you made a convincing argument that CO emissions were shut down at night so concentrations declined but CO2 from respiration continued. Thus, night time data should not be useful for finding an emission ratio.

Response: We totally agree with you that night time CO2 levels are additionally affected by the respiration sources. Although there are influence of respiration sources in the levels of CO2, but not very strong. We have discussed it previously in the revised manuscript as well. Since the wind condition is calm during this period due to no turbulence and most of dominant sources are shut off, the ratios during this period can be useful for broadly understanding about the emission characteristic of dominating sources over Ahmedabad.

I would suggest trying something similar to the analysis of Potosnak et al 1999 that seeks to extract the influence from biosphere and mean diel cycle. (J. Geophys. Res., 104(D8), 9561–9569, doi:10.1029/1999JD900102.)...

Response: It seems to be a good suggestion. However, it requires complete reanalysis of the data in different time bins and beyond the scope of present work. We are extremely sorry.

Page: 32205: In the end the CO: CO2 ratios have such a wide range as to not be very useful at all. Unless you can reanalyse them to bring a narrower estimate it is not worthwhile to show this section. It is curious that the night time data have such a good correlation when the diel cycle analysis suggested that combustion emissions of both CO and CO2 together were shut down. It would help to illustrate the relationship between CO and CO2 in night by colouring the symbols for night-time data differently for time of day in Figure 8a I suspect the daytime values, with low correlation coefficients are not reliable, as you suggest by indicating the importance of CO2 uptake.

When biospheric influence influences the CO_2 mixing ratio you shouldn't bother to try to analyze the CO: CO_2 ratio.

Response: Thank you very much for the suggestion. As per suggestion, we have removed old diagram and added a new diagram (Fig. 2) in the main text, in which the data are segregated in different time windows and coloured according to different seasons. The modified diagram is already shown previously (Page:32204).

As we discussed previously also the CO_2 levels are additionally affected by respiration sources during night time, but not very strongly. We also discussed that CO levels drop very fast during night time, which indicate that there is enough vertical mixing of low CO air from above that once the CO sources are turned off. Hence, this mixing will enhance the correlation during night time, since there are no significant sources, which disturb their levels greatly. Correlation during day time is low only during monsoon season, since biospheric productivity play a large role in influencing the levels of CO_2. But for making the comparisons, we have included the day time values. While during other seasons, correlation is pretty good during day time due to significant atmospheric mixing of all emissions and comparatively lower biospheric productivity. It concludes that during other seasons CO and CO_2 levels are mostly dominated by common emission sources. This whole section is now modified according to previous comments.

Page: 32206: The previous section about CO: CO_2 slopes is rather muddled. It would be more convincing focussing on demonstrating the validity of just the night-time and rush-hour periods that you are using here. Showing the data for entire day just confuses things.

Response: As per the suggestion, now Section 4.5 includes the validity of EDGAR CO emissions from the night-time and rush hour periods measurements only. We have discussed previously also the measurements during these period will show combine influence from all anthropogenic sources mostly. Hence, the estimated slopes for these period will be helpful to validate the anthropogenic CO emissions of EDGAR inven-

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tory. According to that, we have modified our conclusion. We have replaced the fossil fuel emission term by the anthropogenic emissions. It includes all emissions such as vehicular emission, industrial emission as well as cooking sector emissions.

Assuming the discussion of ratios just for the relevant periods is more convincing you can also include some calculation of the uncertainty, which then feeds into providing estimates of uncertainty in the emissions you compute from those ratios and the CO_2 inventory. Uncertainty estimates are critical to include here.

Response: We are highly thankful for the suggestion. The possible causes for uncertainty are the uncertainty in estimated slopes, uncertainty in CO and CO_2 emissions used for EDGAR inventory and uncertainty in the interpolation of the emission of both the gases. We have included the following text in the section due to the uncertainty in slopes. However, due to unavailability of uncertainty information in the emissions of EDGAR inventory, it is not possible to include these uncertainties in the calculation. We are very sorry for that.

“Further the uncertainty in total estimated emission of CO due to uncertainty associated with used slope is also calculated. Using this slope and based on CO_2 emissions from EDGAR inventory, the estimated fossil fuel emission for CO is observed to be 69.2 ± 0.7 Gg (emission $\pm$ uncertainty) for the year of 2014.”

Page: 32235: Consider plotting actual CO and CO_2 mixing ratios to see if the intercepts match the values chosen for background. In the active growing season the biospheric influence will impart a wide range of CO_2 for given values of CO, which is what shows for most seasons. A meaningful slope is difficult to extract in this case. A better estimate of CO_2: CO could be derived by using information from the mean diel cycle analysis to subtract a variable background, or restrict the analysis to just a fixed time of day, or analyze night and daytime separately.

Response: We are very much thankful for your suggestion. According to previous and this suggestion, we have modified the figure significantly, in which we have removed the

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diurnal variation of slopes and restrict our analysis at different time windows separately.

Minor editing 32197 line 25 There must be a missing word in the sentence; 'resulting in concentrations at the surface in the summer compared to the winter.

Response: Thank you very much for pointing out this slip. Yes, it was missing and we have corrected it now.

Please also note the supplement to this comment:
http://www.atmos-chem-phys-discuss.net/15/C13508/2016/acpd-15-C13508-2016-supplement.pdf

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Interactive comment on Atmos. Chem. Phys. Discuss., 15, 32185, 2015.

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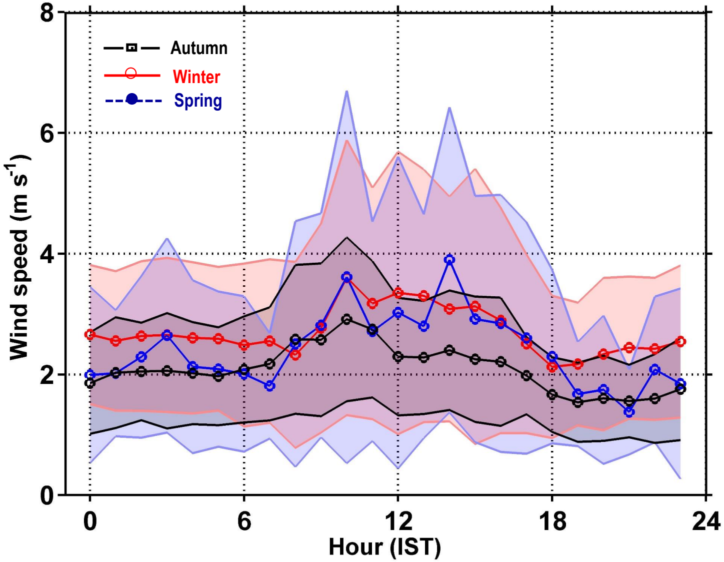

Fig. 1. The average mean wind speed over Ahmedabad during autumn, winter and spring season.

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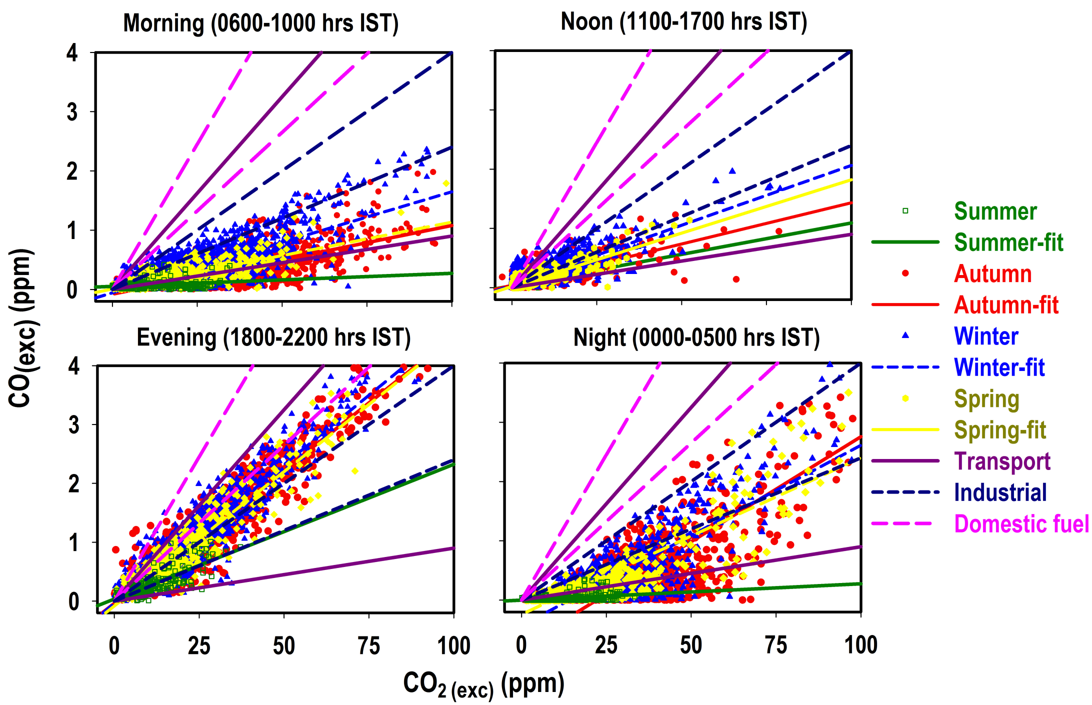

Fig. 2. Scatter plots and regression fits of excess CO (CO(exc)) vs. excess CO2 (CO2(exc)) during morning (0600-1000 hrs), noon (1100-1700 hrs), evening (1800-2200) and night (0000-0500 hrs) hours.

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