Review of ACP-2021-354

This paper presents energy and CO2 exchange at a complex urban forest site in Seoul, Korea. Sub-daily, seasonal and interannual differences in the observed fluxes are analysed and related to climate conditions (e.g. the effect of the monsoon, drought) and characteristics of the site (e.g. land cover, the proportion of road in the source area). Urban-rural differences in CO2 exchange and the role of the urban forest in reducing the urban heat island are discussed. The observed net CO2 flux is analysed in terms of its anthropogenic and biotic components, although the method of partitioning is not described in this paper.

Overall, this is an interesting and useful study. There have been relatively few studies of CO2 exchange made in urban forests (with most similar studies focusing either on non-urban forests or on more built-up urban neighbourhoods). The detailed analysis at this complex site takes into consideration numerous potential factors which could affect the measurements. The comparison with a more built-up urban site nearby is very interesting and demonstrates the impact of surface characteristics on energy partitioning. Assessing two main roles of urban vegetation (i.e. helping to offset CO2 emissions and cool the urban environment) as well as the effect of land management and weather conditions is also relevant for urban planning and broadens our knowledge of interactions in urban climates.

Generally the paper is in good shape (clearly written, well-structured, suitable figures). My main concern is that there is not enough information given about the partitioning method used**.** Although the method (and some of the analysis) is described in a MethodsX article that is often referenced here, to make this a standalone publication more of the important information needs to be readily available to readers of this paper. This also makes the review challenging, since it is difficult to assess the suitability of the approaches and validity of the findings without really knowing how the data have been treated. I have several other queries and suggestions about various aspects - please see below for detailed comments.

Reply: Thank you for your constructive and critical review. We tried to revise our manuscript based on the reviewer's comments without substantial overlaps with our previous publications of Kent et al. (2018), Hong et al. (2020), and Lee et al. (2021).

Kent, C. W., Lee, K., Ward, H. C., Hong, J. W., Hong, J., Gatey, D., and Grimmond, S.: Aerodynamic roughness variation with vegetation: analysis in a suburban neighbourhood and a city park. Urban Ecosystems, 21(2), 227-243, 2018.

Hong, J. W., Lee, S. D., Lee, K., and Hong, J.: Seasonal variations in the surface energy and CO2 flux over a high-rise, high-population, residential urban area in the East Asian monsoon region.

International Journal of Climatology, https://doi.org/10.1002/joc.6463, 2020.

Lee, K., Hong, J. W., Kim, J., and Hong, J.: Partitioning of net CO2 exchanges at the city-atmosphere interface into biotic and abiotic components. MethodsX, 8, 101231, 2021.

Major issues

Methods described elsewhere

L210-1 As the partitioning of Fc is central to some of the results, more information is needed here for this paper to be a standalone publication. A paragraph should be added which summarises the approach used and highlights any important caveats. This will help the reader to understand roughly what has been done to the data (they can still read the MethodsX article for the details) so that they can interpret the results of this study.

Reply: As the reviewer suggested, we revised our manuscript by providing more information on the partitioning method.

There should also be a paragraph which gives an overview of how the gap-filling of Fc was done. This is not an easy task in urban areas with many different controls and a heterogeneous source area. Sufficient information needs to be given here in order for the reader to understand what the annual sums given in Section 3.6 mean.

Reply: As the reviewer suggested, we revised our manuscript by incorporating the gap filling method.

Measurement height needs further consideration

L123-136 The site characteristics described here are difficult to follow. Different distances from the tower are used and several values are given for the roughness length and displacement height without any clear justification for the values chosen. In L195-198 the measurement height is justified based on a relation including displacement height, but it is not clear what displacement height was used to decide this and for some of the values given in Section 2.2.1 this relation is not satisfied. By other commonly used relations (e.g. a measurement height of at least twice the mean obstacle height), the tower would be too low. Careful explanation is needed here so the reader can clearly follow the justification. Since the measurement height is fairly low, the authors may consider adding additional information to convince the reader. For example, did spectra or turbulence characteristics

(e.g. the drag coefficient) suggest the measurements were sufficiently high, or problematic for certain wind sectors? If there is a strong possibility the measurements were made lower than typically recommended, is it possible to say whether this would affect the findings of the paper?

Reply: We estimated aerodynamic roughness parameters using the 1-m horizontal resolution land cover data and should report their values with different wind direction because of different heights of surface bluffs. Please consider that detailed analysis on roughness parameters and integral turbulence characteristics at the site were already reported in Kent et al. (2018). Furthermore, the blending height is pretty low in the skimming flow region because building fraction is less than about 2% within a tower footprint. For better readability, we revised the texts to show roughness length and displacement heights with different wind direction so that we can check the height criteria. We also want to mention that eddy-covariance method is only way to measure turbulent fluxes even in the roughness sublayer over forest canopies and the main footprint covered the forest canopies although lower height may be concern over heterogeneous sources in urban building canyon where there are substantially heterogeneous source and sink distributions.

Minor issues

L26 It's not clear here whether the urban population will increase by 68% by 2050 or whether the urban population will reach 68% by 2050

Reply: We revised the text as the reviewer suggested.

L33-4 Delete 'as opposed to gray spaces' as it is not needed and does not really fit here (gray spaces are also exposed to the range of conditions mentioned)

Reply: We revised the text as the reviewer suggested.

L37 Some examples of harmful effects would be helpful

Reply: We revised the text as the reviewer suggested.

L46-7 May be helpful to explicitly mention air-conditioning here if that is what is implied

Reply: We revised the text as the reviewer suggested.

L51-2 (and other places) What is meant by direct heat fluxes? Surface heat fluxes? Turbulent heat fluxes? Sensible heat flux?

Reply: We revised the text to sensible heat fluxes.

L92 I did not find Appendix A

Reply: We are sorry that appendix was missed, and we added appendix A in our revised manuscript. Thank you for your careful check.

L100-1 What about contributions to respiration from visitors to the park?

Reply: Human respiration is about 0.4 μmol m^2 s^{-1} at most based on the number and staying of park visitors and park areas. We revised the text by adding this information.

L101-3 This sentence doesn't really fit here – merge with the Introduction, Section 3.4, or delete

Reply: We revised the text as the reviewer suggested.

L110-2 As these factors are central to the paper, consider adding some more examples here, such as transport options, fuel types, heating demand, weather conditions, etc

Reply: We revised the text as the reviewer suggested.

L111 The location of the tower does not affect the anthropogenic emissions, but rather the measured fluxes

Reply: We revised the text as the reviewer suggested.

L180 Are these really 'observatories', or would it be more accurate to say 'weather stations'?

Reply: We revised the text as the reviewer suggested.

L204-5 Please add a sentence to justify why negative CO2 fluxes were discarded during nighttime

Reply: Please make sure that vegetative photosynthesis is an only sink and accordingly, negative fluxes during the nighttime are not physically feasible because there are no sinks of CO_2 at night. For better readability, we added the text into the manuscript.

L214 (and elsewhere) the surface energy balance is often mentioned but only net radiation and the

turbulent heat fluxes are analysed. At least the contributions of the storage heat flux (various components) and anthropogenic heat flux need to be considered for an energy balance study. If neither of these were estimated, the discussion should refer to the radiation and turbulent fluxes (and not the surface energy balance)

Reply: We revised the manuscript as the reviewer suggested.

L218 Is 'sensible heat flux' intended rather than 'surface heat fluxes'?

Reply: All turbulent fluxes show mid-summer depression with the seasonal march of the summer monsoon and its related reduction of downward shortwave radiation. This has been reported in many East Asian ecosystems (e.g., Kwon et al., 2009; Hong et al., 2011).

Kwon, H., Park, T. Y., Hong, J., Lim, J. H., and Kim, J.: Seasonality of Net Ecosystem Carbon Exchange in Two Major Plant Functional Types in Korea. Asia-Pacific Journal of Atmospheric Sciences, 45(2), 149-163, 2009.

Hong, J., and Kim, J.: Impact of the Asian monsoon climate on ecosystem carbon and water exchanges: a wavelet analysis and its ecosystem modeling implications. Global Change Biology, 17(5), 1900-1916, 2011.

L231 Should this be Fig 4 not Fig 6?

Reply: We revised the text as the reviewer suggested.

L230-5 Not clear here which are new findings from this analysis and which are being referred to in the Hong and Kim (2011) paper

Reply: Ecosystem in the East Asia shows unique characteristics in their SEB and photosynthetic carbon uptake with the seasonal march of the East Asian monsoon, which include mid-summer depression of surface fluxes and its interannual variability with changes in intensity and timing of heavy rainy season. Our study is the first report this mid-summer depression in the artificially generated forest. Importantly, unlikely to natural forest in East Asia, our study shows that interannual variability of SEB at the SFP is relatively weaker because of artificial management. For better readability, we revised our manuscript.

L235-7 This discussion of QE fits better with the following evapotranspiration paragraph. Perhaps worth mentioning somewhere that QE and ET are equivalent – currently they are discussed almost as two separate variables

Reply: We revised the texts to incorporate the reviewer's comment.

L238-51 Perhaps a sentence or two could be added to strengthen the discussion by considering sub-monthly variation with respect to the timing of the rainfall in July 2017. It would also be helpful to add some comparisons with other urban and forest sites in the literature and potential reasons for differences (e.g. as for the Fc discussion).

Reply: Figure 2, 4 and 5 show monthly variations during the measurement period and we revised the texts for better readability. We also revised our manuscript by adding comparison with other studies.

L245-6 The severity of the drought conditions should be made clearer in Section 2.2.2

Reply: We revised the text in Section 2.2.2 as the reviewer suggested.

L253-61 How were these warming rates calculated?

Reply: We removed these sentences because it is challenging to get statistically significant climatological values from relatively short-term temperature data of < 30 years.

The authors could consider swapping the order of Section 3.3 and 3.2. To me, it would seem more natural the other way around.

Reply: We revised the text as the reviewer suggested.

L262-9 Is this temperature difference significant? Are the results robust (e.g. for the three sites that make up AVG independently)? How were the measurement and elevation heights accounted for? How was it ensured that the differences seen are not due to differences between instruments?

Reply: Please consider that temperature sensors are calibrated every two years and that we are focusing on temperature difference before and after the park construction (i.e., height is not important because measurement height did not change at all during our analysis). Please also consider that because temperature decreases with increasing height typically and the measurement height at the CBD is higher than that at the SD, temperature differences between AVG (currently modified to CBD) and SD will be larger if we account for the height difference. We revised the texts for better readability.

L277 'A possible reason for this' – this should be stated more strongly as the whole of the temperature part of the of the paper is based on the local characteristics being responsible for the

near-surface conditions

Reply: We revised the text as the reviewer suggested.

L287-91 The thermal admittance discussion is not clear, please rephrase

(Our findings indicate that the urban forest has a similar air temperature in the daytime as compared to the rural area (i.e., GP) where has **a lower thermal admittance** because of its location within the airport.) Perhaps consider renaming 'AVG' to something more meaningful to readers, such as 'CBD' for Central 'Business District'

Reply: We removed this sentence for better readability and changed 'AVG' to 'CBD'.

L309-10 It's not clear which results are shown here and which are from Lee et al. (2021). Try to make this clearer so that the reader knows what they can learn from this paper, and what additional information they need to look in the other paper for

Reply: We revised the text as the reviewer suggested.

L315 A couple of references showing this in natural ecosystems would be helpful here

Reply: We added several references here as the reviewer suggested.

L328-9 It is difficult to see this relation in Fig 9. Perhaps delete and rely on the reference to Lee et al. (2021)

Reply: We revised the text as the reviewer suggested.

Fig 3 first seems to be referenced in L335, after Figs 4-10. Given the importance of land cover around the tower in this section of the analysis, it would be helpful to add a subsection to 2.2 where the site characteristics are clearly described in preparation for these results. There is some information spread through Section 2.2.1 at the moment but this should be extended and more clearly described so the reader gets a good understanding of the site early on. The analysis in L346-355 may fit better at the start of Section 3.4 as it gives a general overview of the different processes in different parts of the source area.

Reply: We revised the text and added a figure as the reviewer suggested.

L342 Should Fig 10b really be referenced here?

Reply: We revised the text as the reviewer suggested.

L344 Emissions from the park facility are mentioned here for the first time. It would be good to include this in the site description and to discuss the effect on the results. Are these emissions from a single nearby building responsible for a large proportion of the measured Fc, and if so, what implications would this have for the reliability of the measurements and the annual total CO2 flux? Is it possible the Tair and QE measurements were also affected by these emissions?

Reply: As the reviewer suggested, we revised our manuscript by adding information on building emissions in the site description. Please consider that there is only a building within the tower footprint and this building emission occurs only in winter because of hot water and space heating. Our estimations on anthropogenic emission from vehicle and building show good correlation with inventory data such as visitor counts, traffic volume, and natural gas consumption in the park (Lee et al., 2021). Also, we discussed that our partitioning indicated that building emission was important contribution to net CO2 exchange in winter (Fig. 13). Please also consider that air temperature is considered in the flux partitioning method.

L402-407 This paragraph is not very clear. Please rephrase

Reply: We revised the text as the reviewer suggested.

L415-516 The Fc results are set in context using other studies. It would be good to do the same for the UHI and energy balance results.

Reply: We revised our manuscript for comparison of our results with other studies. We added a table to summarize surface fluxes at several urban sites of the similar vegetation cover. We expanded our comparison of UHIi to the study in Korea by Hong et al. (2019a) that used the Gimpo airport weather station as the reference. Please also consider that it is hard to make general comparison with other previous studies because they used different rural or suburban sites when they calculated UHI.

L463-5 Here the text suggests that the flux partitioning method was proposed in this paper which is not the case. There is no description of the method in this paper. Please amend.

Reply: We revised the text as the reviewer suggested.

Similarly in L514-6 it should be made clear that the partitioning method is from the Lee et al. (2021) paper and not developed in the current paper.

Reply: We revised the text as the reviewer suggested.

L471-3 Consider mentioning irrigation here

Reply: We revised the text as the reviewer suggested.

L483-4 It is not clear if the 'rule of thumb' is for this study or more generally. Probably replace 'rule of thumb' by 'For this study'

Reply: We revised the text as the reviewer suggested.

Table 1 It would help the reader to write the descriptions of the LCZs here instead of subscripts with the codes which most readers would have to look up elsewhere. 'Flux' is too general in the 'used variables' column. Please be specific (or this column could probably be deleted). What to the heights represent – measurement height above ground, elevation?

Reply: We revised the table as the reviewer suggested.

Table 2 As mentioned above details are needed about the gap filling procedure. Do these totals correspond to the source area (i.e. dependent on the wind direction distribution) or neighbourhood averaged values? Were the energy fluxes here gap-filled analogously to the CO2 fluxes or were totally different methods used? Similarly for Fig 13, do these bars correspond to the source area composition (i.e. are they affected by wind direction) or has the wind direction dependency been accounted for by the gap-filling procedure.

Reply: We revised the table as the reviewer suggested by adding more information on the gap filling and flux partitioning method.

Figure 3 How was the dominant wind direction decided? Is this the modal value? Change 'ratio' to 'proportion'. Currently Fig 3 is not used very much in the text – as suggested above developing this

part to give a clearer idea of source area characteristics and variability would be helpful for the reader. As an example, the proportion of road in the footprint could be added.

Reply: Our estimation is based on wind rose analysis and we replaced this figure with a wind rose

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Fig 4 Consider adding a row with incoming shortwave measurements as you have the data.
Reply: We revised the table as the reviewer suggested.

Fig 8 It would be interesting to explore the scatter in this graph and indicate which points correspond to which month in which year. What does the dashed line represent? Is a simple linear regression of y against x appropriate when both x and y have appreciable uncertainties? Why are there no error bars shown in the x-direction?
Reply: We revised the table as the reviewer suggested. We added error bars in x axis and applied for a linear regression to consider uncertainties in x and y.

Fig 9 The caption is difficult to follow and should be rephrased. The gap due to power failure should be mentioned in the Methods section.

Reply: We revised the table as the reviewer suggested.

Fig 10 Why was this monthly separation chosen between panels (a), (b) and (c)? It might help to indicate the road sector on this plot.

Reply: We revised this figure by adding the road sector. Please consider that there are apparent changes in each component in carbon balance equation on monthly basis.

Fig 11 It would be useful to add why EB does not feature in the equation in L834

Reply: Please consider that EB occurs only in winter because of hot water and space heating supported by natural gas consumption as we mentioned in our manuscript. Please also consider that light response curves of NEE and GPP are comparable to other vegetative canopies. We added this information in this figure caption for better readability.

Fig 12 It is not clear what the reference means here. What do the dashed lines represent?

Reply: We discussed this issue in the main texts and added the information into the figure caption too.

We revised all the very minor and language issues below as the reviewer suggested. We appreciate the reviewer's efforts for our manuscript. Thank you four your kind work for our manuscript.

Very minor/language issues

Generally the standard of English is very good, though there are a few places where more natural phrasing could be used. I have made some suggestions here:

L9 'two years of surface fluxes'

Reply: corrected.

L18 'than for typical'

Reply: corrected.

L21 'if the goal is lower CO2 emissions…' or 'when aiming to reduce CO2 emissions…'

Reply: corrected.

L24 'Cities comprise' or 'Cities make up'

Reply: corrected.

L31 'urban forests'

Reply: corrected.

L35 'during urban redevelopment'

Reply: corrected.

L36-7 'and overcome their maintenance costs'

Reply: corrected.

L39 'have been addressed'

Reply: corrected.

L43 'for longer than'

Reply: corrected.

L44 'contribute to reducing'

Reply: corrected.

L53 'have reported on the surface'

Reply: corrected.

L55-6 'Forests can even produce a warming trend as a result of their low albedo'

Reply: corrected.

L73-4 'It is challenging to partition Fc into individual sources and sinks in urban areas because'

Reply: corrected.

L78 'carbon cycles'

Reply: corrected.

L81-2 Not clear, could delete the text 'where a hot… …warming trends'

Reply: corrected.

L83 'based on partitioning of FC data measured by eddy covariance'

Reply: corrected.

L128 'south and west sectors (120-330°)'

Reply: corrected.

L129 'and roads lie outside of the park'

Reply: corrected.

L137 'The roads'

Reply: corrected.

L166 'for comparative analysis because the sites are'

Reply: corrected.

L207 Delete 'after the processes'

Reply: corrected.

L208 'Here we partition the measured Fc into'

Reply: corrected.

L209-10 'This study applied a statistical'

Reply: We revised the sentence including this line based on the major comments.

L250 'is unknown' or 'has not been quantified' would be clearer than 'is inexplicit'

Reply: corrected.

L267 'when photosynthesis is highest. Our results'

Reply: corrected.

L271 'also produces'

Reply: corrected.

L309 Define EVI

Reply: defined.

L310-1 Move 'accordingly' to the start of this sentence

Reply: corrected.

L312-3 'absorbs more CO_2 than is emitted by local sources and Fc is negative only during the summer daytime. Because of…'

Reply: corrected.

L320 'Greater reduction'

Reply: corrected.

L332 'The seasonal Fc variation also depends on…'

Reply: corrected.

L335 Delete 'particularly'

Reply: corrected.

L348 'further indicate the'

Reply: corrected.

L359 'contrast to Fc in high-rise high population residential areas… that does not respond to PAR'

Reply: corrected.

L318 ‘from a suburban area with about’

Reply: corrected (L381).

L425 Delete ‘cumulative sum of the’

Reply: corrected.

L456-7 ‘method in order to examine the role’

Reply: corrected.

L462 Suggest deleting ‘and was redeveloped from a racetrack and factory in the mid-2000s’ as this is not really relevant for the conclusions

Reply: corrected.

L479 ‘a typical diurnal’

Reply: corrected.

L418 ‘and the time of the minimum is delayed’

Reply: corrected (L481).

L500 Delete ‘Eventually’

Reply: corrected.

L508 ‘forests have important impacts on air…’

Reply: revised.

L810 Move ‘in summer’ after ‘AVG and SD’

Reply: corrected.