Response to Reviewer 2

We thank the reviewers for the comments and the updated manuscript is marked with deleted parts crossed-out in red and added parts in blue with **original text in black**. Greens are our responses and reviewer2's comments are *in black italic*.

Prior to the point-by-point response to all the comments, we would like to emphasize that there are no significant changes in our conclusions upon updating our analysis with the two key suggestions from reviewers 1 and 2, which are adding more stringent filtering criteria for turbulent flow statistics and using 90 % flux confinement in footprint analysis. All the related figures and numbers were updated accordingly in the main text and supporting information with tracked changes. Most of them that are related to the response to the comments are presented here but not all for the conciseness of this document, especially for the numbers and small changes.

*Comments:*

*"Insights on estimating urban CO2 emissions using eddy-covariance flux measurements"*

*Kyung-Eun Min et.al,2022*

*General comments*

*This manuscript try to quantify CO2 emission strengths of individual urban activities (vehicle, industry, heat generation et.al.) based on less than one year measurements with Eddy-Covariance (EC) method at Gwangju, Korea. The author estimated CO2 emission factors (EFs) of Traffic/Industry/Heat from the EC measurement, while the plants influence on CO2 exchange including photosynthesis and respiration can be estimated as the net balance of total emissions among all activities with observation (for the estimation of EF of vegetation). Based on their EFs estimations, they found that the annual CO2 emissions of traffic and space heating were more than 2.5 times higher than those of the emission inventory for Gwangju in 2017-2018.*

*1. However, this experiment setup and data are not reliable. The CO2 flux measuring system was installed on the helideck of the Gwangju city hall, so the building's effect on the EC measurement could not be ignoring. The results are not robust.*

We analyzed our data with caution due to the possible distortion caused by the city hall building itself. As described in the original manuscript, the CFD (computational fluid dynamics) model constrained for real architectural information of the building is used for careful data selection for further analysis.

As a proof of legitimacy in our measurement, we added the spectral analysis results for the wind sector used for *ESs* (emission strength) assessments which showed no drastic alterations in eddy break down with a theoretical slope of -4/3 as shown in Figure S3, which can be used as an evidence of reliability of our measurements for further in-depth analysis. The main manuscript has also been updated to refer Figure S3.

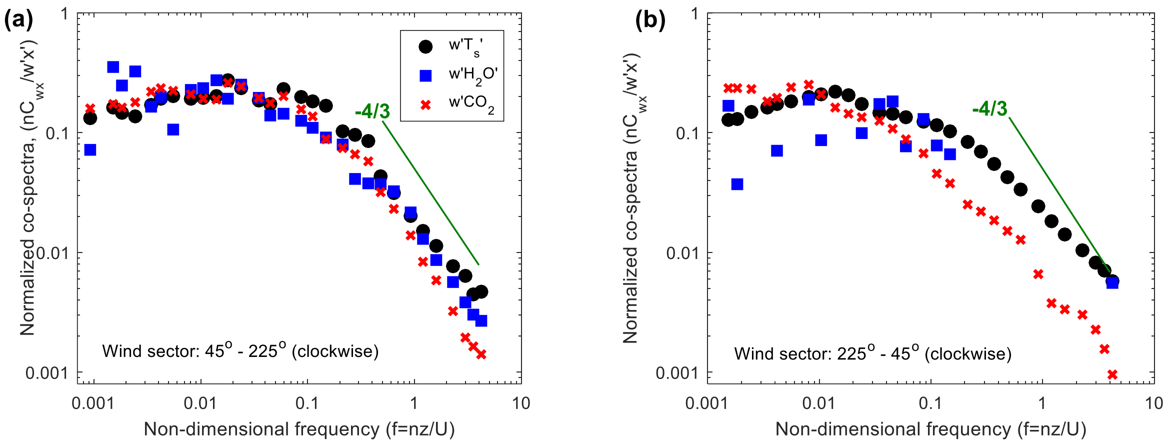


**Figure S3. Co-spectral analysis results for the filtered data for in-depth analysis throughout the manuscript for (a) used wind sector (45°-225 °) and (b) the other (225° -45°). Normalized co-spectra by individual flux of sensible heat (black circle), water (blue square) and CO2 (red cross) against non-dimensional frequency (multiplied by measurement height, z, and normalized by wind speed, U) exhibit a slope of -4/3 as predicted in theory for (a) but not for (b).**

(Line 251) In addition, this is supported by the co-spectral analysis result of sensible heat, water and $CO_2$ fluxes shown in Figure S3 which exhibits a theoretical decaying rate of -4/3 in the inertial subrange only in 45°-225 ° wind sector.

*2. On the other side, there are lot of EC towers to measurement the Co2 flux in city since the beginning of 21st century, and some sites have collected more than 10 years dataset. CO2 emission factors (EFs) could not be used to other city as a universal parameter for the estimation of the annual co2 flux in the city.*

We are not sure about how we can find the "a lot of EC towers to measure the $CO_2$ flux in city since the beginning of 21st century, and some sites have collected more than 10 years of dataset" based on the first part of these comments. As far as we know, there are very limited number of existing publications on the urban $CO_2$ EC flux measurements as reviewer1 pointed out due to the difficulties not only in measurements but also in interpretation. In addition, the significance of our manuscript is not only limited to reporting the EC flux of $CO_2$ but also evaluating *ESs* (Emission Strengths) with site-specific characteristics. Even those existing long-term measurements, as mentioned on the last part of this comment, the *ESs* estimated from other cities cannot be applied to other cities as we also pointed out in our manuscript.

Additionally, we would like to emphasize the beauty of in-depth analysis with relatively short-term measurements in urban than the traditional long-term agricultural field application of EC technique, by suggesting a method to ease out the seasonal changes in $CO_2$ emission characteristics using the difference in day of the week pattern. Human activities in urban setting likely change over long-term period, like 10 years, especially in a developing country like Korea where active urban expansion happens. Its $CO_2$ emission pattern is altered through changes in various parameters such as traffic congestion condition related to changes in traffic volume, industrial activities in line with economic conditions, number of residents and their energy use, land use type (i.e. vegetation cover, bare land and open water, etc.), etc. Thus, in assessing $CO_2$ emission in urban setting, relatively short-term scale approach is more realistic and beneficial for establishing mitigation strategies in climate change.

On the other hand, we somewhat agree on reviewer2's point about "*CO2 emission factors (EFs) could not be used to other city as a universal parameter for the estimation of the annual* *co2 flux in the city*". If that *ESs* refers to traffic, we cannot agree more as we also described in our manuscript. Thus, the word choice of *EFs* (Emission Factors) is not the best one as reviewer1 pointed out. Thus, we updated our terminology to *ESs*, hoping that our society will have more consensus on this issue. Meanwhile, for some of the *ES*s (i.e. heating, plant uptake), we may be able to use such as general parameters accompanied with detailed information (i.e. heating types and species by species vegetation cover).

(Line 103) In addition, long-term measurements of $CO_2$ fluxes are not necessarily linked with accurate *ESs* since urban utilization changes rapidly, in particular in developing countries.

*3. By the way, the model to simulate the co2 flux over city has been published (Jarvi, L., et al.(2019),JGR: Atmos.).*

We appreciate the suggested literature and we included it in our manuscript as below.

**(Line 56)** In addition, modelling attempts have also been made to study the variability and magnitude of carbon emissions and sinks in high spatial and temporal resolution (Jarvi et al., 2019). Specifically, the $CO_2$ model accounted for both anthropogenic and biogenic emissions over the city using combination of sources such as high-resolution airborne lidar-derived land use data and mobility data.

*4. This manuscript is not suitable to be accepted by ACP.*

We think we have fully addressed all the concerns of reviewer2 through our responses which are sufficient enough to highlight the significance of our work to contribute to the knowledge expansion in our atmospheric society through publication in ACP.

*Specific comments*

*1) L123-134 "The CO2 flux measuring system was installed on the helideck of the Gwangju city hall,……Our EC system was installed outside of inertial sublayer …and sufficiently lower than the planetary boundary layer.", is it correct? The measurement is set in Gwangju city hall (90 m above the ground – building height: 85 m, helideck: 3 m and measuring system structure: 2 m), so it is not satisfied the guideline on the flux measurement in the city. The building's effect on the flow has large influence on the EC measurement.*

We thank the reviewer for pointing out our mistake. "~ outside ~" should be "~ inside ~". For better expression, we updated the sentence as below.

(Line 130) Our EC system was installed outside ~~of inertial sub~~the roughness layer ~

*2) L166-167 "footprint boundaries were defined to confine 70% of average total flux during the measurement period.", usually we use the footprint boundaries to cover 90% of average total flux ".*

The degree of confined fraction is not a fixed number. The default value in SmartFlux 2 software is 70 %.

However, to reflect the concern on this aspect, we updated our analysis with footprint confinement of 90 % fluxes as shown in updated Figure 2. Following the analysis, most of the year round $CO_2$ estimations were updated in the main text in section 4 and Table 2 as well as in land use fractions in Figure 2 with corresponding descriptions.

(Line 166) Here, footprint boundaries were defined to confine ~~7~~90% of average total flux during the measurement period. Detailed calculations and parameterizations are described in S3~~2~~ of the *SI*~~Supporting Information~~.

*3) L172-174 " To assess the quantitative contributions of the individual sources, the wind directions were split into two sectors; (1) the Eastern Industrial Area (EIA, 45º-100º) and (2) the Southern Green Area (SGA, 100º-225º), based on whether or not the fetch includes the automobile production plant and urban vegetation .", it is too simple to assess the quantitative contributions with two sectors division, due to the complex flow field in this city. So the EFs estimation has too large uncertainty.*

We are not sure what "complex flow field in this city" means. The topography of the city within fetches are pretty flat (please see more on the response related with your 4th comment). By considering the difference in weekend and weekday $CO_2$ fluxes for the same wind sector, the detailed variations are expected to be canceled out even if we are not sure about the existence of "complex flow" within our study area. In addition, as you can see from the polar plot in Figure 4, there are no distinct sources of $CO_2$ flux in EIA and SGA other than what has been expected.

*4) Gwangju city is located in a basin area, while there is a more than 1000m High Mountain in the east of the city. The local circulation due to the terrain should be occurred sometime during the season, and may be interaction with the urban heat island (UHI) in Gwangju city. So the co2 flux measurement may be also influence by the two circulation. This manuscript didn't consider any information on the topic.*

In fact, Gwangju is located in a semi-basin which is open in north-north-east to south-south-west. As shown in Figure S1, the Mudeungsan Mt. referred by reviewer2 is located more than 10 km away from the 90 % flux confined fetch. Within the footprint, the topography is relatively flat. This information has been added in the supporting information as S1.

(Line 11 in SI) S1. Topographical setting of study area

Gwangju is located in a semi-basin which is open in north-north-east and south-south-west direction. As shown in Figure S1, our study area is relatively flat (47±25 m, 3 hills up to 100 m in height are located close to the end of 90 % confined flux fetch where the radius of the footprint is close or less than 4 km); the small hills especially in southern area are lower than the mean building height throughout the fetch. The Mudeungsan Mt. and its foothills (1187 m ASL) are located more than 10 and 4 km away from the footprint.

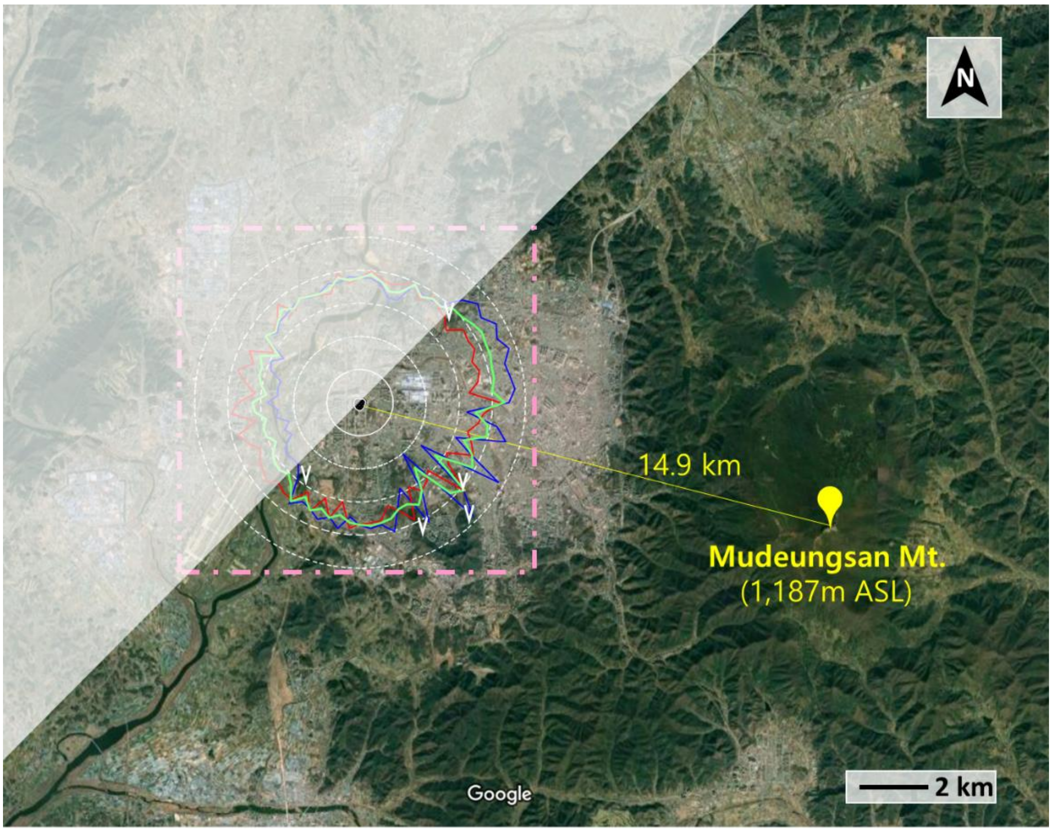


**Figure S1. Topographical setting of study area with 90% flux confined footprints Kljun (2004), Kormann and Meixner (2001) and their averages in red, blue and bright green lines. The white V markers are the hills close to 100 m in height and the yellow balloon is the location of Mudeungsan Mt. Dotted dash pink line refers to the area shown in Figure 2(a) in the main text.**

In regard to the heat island, there are two possible alteration exits, one for the local circulation changes as the reviewer pointed out and the other for the storage. For the circulation alteration, as mentioned in our response in 3rd comments, taking the difference within a week time frame will lessen this concern. To add more clarity on this aspect, the sentence below was added.

(Line 181) In addition, the concerns about possible complex circulation owing to urban heat island phenomenon likely lessen in DOW difference.

In regard to heat accumulation near the surface, it likely matters to heat flux measurements than to $CO_2$. In order to quantify the heat flux exchange, storage corrections are necessary for urban setting. Heat island effects are not directly related to $CO_2$ exchange. However, we also mentioned the possible underestimation in $CO_2$ emission due to the limitation in vertical $CO_2$ concentration gradient measurements in line 21 and 319.

*By the way, the wind rose (daytime or nighttime) during 2017-2018 could not be found in the text.*

We added the wind roses in *SI* as Figure S10 with related descriptions as below.

(Line 273) Wind roses during the study period are shown in Figure S10 for wind distribution in the study area.

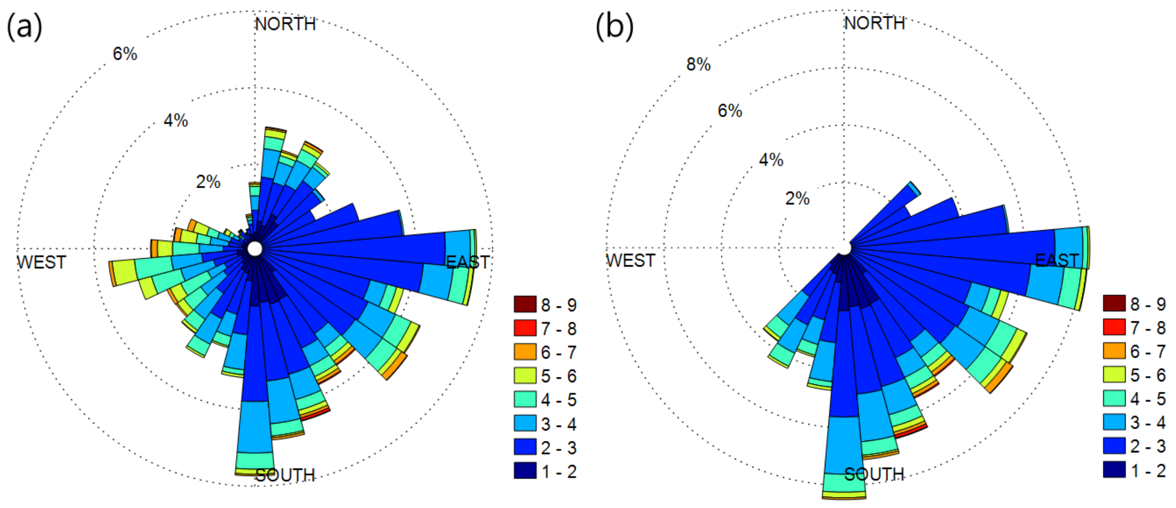


**Figure S10. Wind roses of filtered data from (a) all direction and (b) target wind sector for this study.**

## *Reference*

Järvi, L., Havu, M., Ward, H. C., Bellucco, V., McFadden, J. P., Toivonen, T., Heikinheimo, V., Kolari, P., Riikonen, A., and Grimmond, C. S. B.: Spatial modeling of local-scale biogenic and anthropogenic carbon dioxide emissions in Helsinki, J. Geophys. Res.-Atmos., 124, 8363–8384, https://doi.org/10.1029/2018JD029576, 2019.