Reviewer comments and suggestions to the INFLUX EC data paper

Editor Comments

Thank you for submitting your manuscript to Earth System Science Data. We have now received two reviews: one strongly supportive, and one critical, particularly regarding the applicability of eddy covariance methods in heterogeneous urban settings.

While we acknowledge the valid methodological concerns raised, we believe the long-term, multi-site dataset presented here offers significant value to the research community, especially if its limitations are transparently addressed. In line with ESSD's focus on data availability and transparency, we request that the authors respond thoroughly to both reviewers' comments before further consideration.

In particular, please address the following points in your response:

- A substantially expanded discussion of the limitations and applicability of eddy covariance methods in complex urban settings, with appropriate citations.

In the introduction, we have included a discussion of the limitations of the eddy covariance methods in complex urban settings and stress, while the underlying assumptions of eddy covariance are likely seldom (if ever) truly met in these environments, these measurements are invaluable, given that it is within these complex areas where a large portion of the global population resides.

- A detailed response to Reviewer 1's concerns, especially regarding site selection, heterogeneity, and justification for the use of EC at these locations.

We have responded to and addressed many of Reviewer 1's comments and concerns, and we hope that the provided response and the alterations made to the text are sufficient to satisfy all parties.

- Inclusion of all missing metadata (site coordinates, zero-plane displacement height, aerodynamic roughness length, surface characteristics, etc.) as requested.

We have included metadata with the data sets shown in Table 5. These data provide site coordinates and flag thresholds, such as friction velocity thresholds, etc. We have also provided a first-order estimate of roughness length and displacement height for all three mixed urban towers (see Table 4). Other requested variables for the mixed urban towers have not been included, as a single value would be insufficient to capture the heterogeneity that exists around these towers. For example, albedo changes from one direction to another. This is also the case for the roughness length and displacement height; however, we have provided a first-order estimate, given the importance of these length scales in *footprint modeling. Several remote sensing datasets are presented in the text and can be easily obtained by individual investigators for use in describing the site's heterogeneity. This approach is more suitable than attempting to provide a single value for the site, and we argue that, in general, it is an appropriate strategy for making measurements in the urban environment, which is never truly homogeneous. While a few of these data products are mentioned throughout the manuscript, a formal list of these data products has not been included, as we believe this falls outside the general scope of this manuscript.*

- Clarifications on data processing methods (e.g., friction velocity thresholds, handling of missing meteorological data, rationale for excluded corrections).

We have included further elaboration on data corrections in the absence of separate meteorological variables, as is handled by the EddyPro software used in this manuscript, and provided friction velocity thresholds with the metadata files of each individual site.

- Reorganization of figures/tables as per standard formatting.

We believe this should now be addressed and corrected in the manuscript.

We believe that a careful and complete response to these points is essential for further evaluation. Please upload a point-by-point response to each reviewer's comment.

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Reviewer 1's Comments

This manuscript introduces the turbulent flux measurements made by eddy covariance during the long-term Indianapolis Flux Experiment (INFLUX). These measurements aim to investigate the exchange of carbon and energy between Indianapolis' urban surface and its surroundings with their overlying atmospheres.

The experiment is still ongoing, with two eddy covariance flux systems. Over the course of eleven years, up to four systems have operated simultaneously, three over built-up areas and the rest over agricultural fields and turfgrass-covered ecosystems. It is one of the few initiatives that has run a large number of eddy covariance flux towers over an extended length of time. In that respect, this publication is appropriate for ESSD, with the goal of making the collected data available to the public for future research.

However, despite certain omissions in the observation site's description, there is a major problem with the urban flux systems. The three systems were installed in sites that do not meet the eddy covariance working assumption (see specific comments to Figures 7, 8, and 9). The eddy covariance method requires a uniform landscape in terms of topography, urban morphology, building heights and densities, and distribution of emission sources and sinks. As explained in the chapter on eddy covariance flux measurements in the IG3IS Urban Greenhouse Gas Emission Observation and Monitoring Good Research Practice Guidelines (GAW Report No. 275), this entails having streets with similar traffic and houses with similar characteristics all around. Large factories, parking lots, parks, and any other major distinctive emission source or sink within the footprint should be avoided. According to this reviewer's experience, siting an eddy covariance flux tower based on these considerations is challenging, as cities are inherently heterogeneous; nonetheless, proper sites can be found where such heterogeneity is relatively homogeneous.

Based on previous publications and participation in various forums, this reviewer is familiar with the authors' arguments in favor of installing eddy covariance flux towers in extremely heterogeneous urban landscapes. These arguments have not convinced him, and while the results may have some consistency, he does not believe they are robust enough to contribute to determining greenhouse gas emissions in cities.

This reviewer recognizes the personal and financial resources required to run this monitoring network. However, he cannot endorse the installation of flux towers in such conditions. If the manuscript is published, he would use it as an example of what not to do when applying the eddy covariance method on urban surfaces.

We understand the reviewer's concerns, but we believe that these sites have already proven their scientific value. We argue that urban systems are inherently heterogeneous *and that we are compelled to adapt our measurements and models to these environments. Asking the complex urban environment to adapt itself to our theoretical wishes will not, in our opinion, advance our understanding of these inherently heterogeneous systems. One of the authors of this manuscript expressed his views on this topic in GAW 275, which, in any case, is only a guidance document and does not provide any quantitative or rigorous proof regarding deployment methods.*

We also note that the applications of these sites go far beyond simply describing urban greenhouse gas emissions. Urban turbulence exists. We need to measure it and understand it.

General comments

All text. Figures and tables must be added after they have been mentioned in the text, not before. Please double-check that all abbreviations have been defined in the text before using them.

We thank the reviewer for pointing this out and have reorganized to conform with journal formatting.

Missing data in the general context of Indianapolis: height above sea level, climate (Köppen classification), annual rainfall, and mean, min, and max ambient temperature and relative humidity.

We have added subsection 2.1 to the text to further elaborate on certain climatological aspects.

Missing data for each flux tower: latitude and longitude.

This information is included in the site metadata

Missing data for each urban flux tower: zero-displacement height, aerodynamic roughness length, normalized wall surface, canyon height-to-width ratio, sky view factor in the middle of the street, mean albedo, surface emissivity, and population density.

We have included roughness length and zero-plane displacement for all three mixed urban towers (please see Table 4), but stress that these are first-order estimates. Regarding these other requested data, we have omitted them from the manuscript as most vary around each of the towers, and providing a single value would be insufficient for interpreting the data. A wealth of resources is available, and some of these data sources (e.g., LiDAR data) have been noted in the text. We have excluded a list of potential data sources from the manuscript, as we believe they are outside the scope, and instead leave gathering data of interest to individual users based on their scientific needs. As described above and in the *text, we argue that we are now in an era of abundant high-resolution data that can be used to create realistic descriptions of complex urban environments. Defining a heterogeneous site with a single set of parameters would be misleading. Providing the data for each site would duplicate existing data sets that we have not created. We argue that the best approach is to instruct investigators to obtain the spatial data needed for their purposes. This does make simple syntheses across sites more difficult. We note that efforts are already underway to classify flux tower sites as homogeneous vs. heterogeneous to assist in such efforts (e.g., Chu et al., 2021). We acknowledge this movement and note that Chu et al. (2021) document that many sites already in our datasets are, in fact, substantially heterogeneous.*

Specific comments

12-13. Indeed, the number of urban eddy covariance flux towers remains limited in comparison to the number of flux towers in natural ecosystems, but I would not call them uncommon. The number is increasing, albeit gradually.

We have removed the wording from the abstract.

14-15. Rewrite. Indeed, you have installed flux towers in eleven sites, but only three of them have run for an extended period of time; the other eight have run for only a short time. Reading the abstract, one could assume that all eleven flux systems have operated simultaneously.

We have made it clear that these sites have not all operated simultaneously. We are not trying to create a classical long-term monitoring network.

17. '... and separate anthropogenic from biogenic contributions.'

We have removed this section.

44. Define footprint and source area.

I have added a plain language definition for the footprint area in line 46

55. Do you mean flux contributions from a number of emission sources and sinks? Remember that the eddy covariance method measures integrated fluxes from a myriad of emission sources and sinks within the observed footprint.

We agree with the review, and the initial version was indeed confusing. I have revised the wording.

80-81. But it provides valuable information for assessing the accuracy of bottom-up emission inventories, at least for a particular area of the city. Typically, the footprint size observed by urban flux towers is similar to that of grid cells used to build emission inventories for regulatory purposes.

We agree that single towers are valuable. The text states this fact already. The resolution of flux models and inventories evolves with time. We have not edited the manuscript in response to this comment.

112. The term ‘tall tower’ is subjective. Consider replacing it with ‘urban tower.’ Flux towers over 100 m tall have been installed in London, Beijing, and Zurich, but this reviewer disagrees with them because they fail to meet the method's fundamental assumptions.

We agree that “tall tower” is subjective and ambiguous, and we thank the reviewer for pointing this out. We also feel that “urban tower” alone would be misleading since our turf grass sites are very much urban. We have changed the terminology to describe the footprint characteristics. We now use the term “heterogeneous urban tower” to describe sites in the city that clearly combine anthropogenic and biogenic fluxes. This label is also somewhat ambiguous (e.g., even turfgrass open to other ideas for distinction will be heterogeneous). But we believe this change in terminology helps to describe the nature of these sites within the network more precisely than “tall towers” or “urban towers.”

116. Figure 1. See comment above.

The wording of the figure has been revised to align with the comment above.

142. Table 1. The site identifications are not practical. Don't expect readers to memorize what kind of site each one is. Add identifiers to mark which correspond to turfgrass, croplands, and built-up areas.

We have included a categorical aspect to the table. We hope users will be able to identify the category to which a particular tower belongs by referring to the section where it is explained.

142. Table 1. Include plant species for the agricultural and turfgrass sites. For the latter, indicate the grass type. It would also be nice to include the soil characteristics for each site, including soil texture and pH, bulk density, and total organic carbon content.

Plant species were included for the agricultural sites; for this, we point the reviewer towards Figure 5. Formal species composition for the turf lawns was not conducted during site deployment. Communication with local managers indicates that the sites are primarily composed of C3 grass species. Understand that while having a suite of other variables regarding soil properties could be helpful, we were unable to obtain all of these data due to the limited resources available.

145. Table 2. Only two sites were equipped with net radiometers, meaning that the energy balance partitioning wasn't assessed at the other nine sites.

145. Table 2. Why were meteorological probes not included in the three urban flux towers? They are necessary to correct the virtual temperature obtained from the sonic anemometer and could be used to indirectly calibrate the IRGA water vapor records. How were the periods affected by precipitation identified?

We deployed what was possible and most impactful, given the limited resources available. This is true of any experiment. Meteorological variables at one level on one tower have modest value in the presence of existing weather measurements and reanalysis, and they are not essential for flux calculations.

Regarding data processing, we have included a short additional statement in Section 2.3, which articulates that the translation among sonic, virtual, and air temperatures is performed using an iterative approach employed by EddyPro, where only the sonic and gas analyzer measurements are used for iterative correction (see line 239). Periods of precipitation are identified using the signal strength flags, given the impact of precipitation on the Licor's signal strength.

152. Define SFTP.

This has now been defined. Please see line 213

204-205. Provide a reference. Similar to other authors, this reviewer has run urban flux towers and has proved that well-designed towers installed in proper locations meet the eddy covariance assumptions.

We thank the reviewer for this point. We agree that some assumptions are violated, and we have attempted to clarify our statement. We should not have written, "seldom…meet the underlying assumptions of EC." This is incorrect. Heterogeneous sites do not violate "eddy covariance assumptions." They do violate approaches to data interpretation that a given scientist brings to their work. The eddy covariance data collected in a heterogeneous setting are valid. The interpretation of these data requires different approaches than measurements collected in, dare we say, anomalously homogeneous urban settings. We have revised this text to note that the classic assumptions underlying the interpretation of EC fluxes in more homogeneous locations are not applicable to some of the INFLUX sites, and have made it clear that these sites do not meet those assumptions. We also no longer claim that this is true for any "tall tower" in an urban environment. Please also see the added paragraphs to the introduction section.

206-208. To avoid this issue, urban flux towers must be placed in neighborhoods with relatively homogenous building morphology and emission sources and sinks homogeneously distributed across the observed footprint.

Thank you for your comment. We agree that more homogenous sites may yield to simpler methods of interpretation. We choose to embrace this issue as intrinsic to the urban environment, and argue that we have the ability to work to understand the complexity and turn it to our advantage.

223. How do you define weak turbulence?

The author agrees with the reviewer and has revised the wording to clarify that we are referring to weak, mechanically driven mixing, which is approximated by the u-star filter. Please see line 287.

232. Figure 4. Make reference to Table 3 to indicate which filters were included in each filtering set. It would be nice to include the percentage of remaining data points after each filtering set.

We thank the reviewer for their comments and have now included percentages as requested and clarified the references using Table 3.

239. Table 3. Which was the friction velocity threshold? Define 'hf w' and 'hf CO_2.'.

We have included these data in a metadata file accompanying the associated datasets described in this manuscript, and defined 'hf' in the Table 3 caption.

267. Figure 5. At the bottom you may add the total daily flux for each site.

We appreciate the comment, but have decided to exclude these values given that the figure is already quite busy.

291-292. Which was the source for the boundary layer height required as input data by the FFP model?

Thank you for pointing out this missing information. We have now included the reference for ABL height, which comes from ERA5 reanalysis. See line 360

341. Table 4. Define LCZ. Add units for RE density. Is it possible to split the RE density in trees and buildings? Similarly, could you include the mean height and variability of each one? In the case of trees, it would be nice to indicate the main species. Also, indicate the turfgrass species and type.

The author appreciates the review's comments and has defined LCZ, which had not yet been defined. The RE density is dimensionless, also known as the planar area index, which *is likely more familiar to readers, and has been renamed accordingly to avoid further confusion. It is possible to manually designate the trees and other vegetation from the built objects. We could do this with considerable additional work, but we do not have a clear need for this information, and we cannot anticipate or meet the needs of all flux data users. If data users wish to understand the distribution of vegetation and built objects around the tower, for their research, we recommend and have provided the LiDAR data citation from which they can begin their inquiry. Inquiries with site management at the two turfgrass locations indicated that both lawns are predominantly composed of C3 species. No formal species analysis was conducted for the vegetation around any of the towers, so we are unable to provide species-specific information around the mixed-urban towers.*

341. Tall buildings are likely to obstruct the flow and alter the eddy spectra at sites US-INc and US-INf based on the maximum height of the roughness elements within the measured footprint in all directions.

The LiDAR data used to calculate these statistics includes all built objects (communication towers, lamp posts, buildings, etc.). At US-INf, these maximum height values are derived from isolated objects, such as towers, whose footprints are on the order of 1-3 meters. At US-INc, these large values are observed from buildings located more than 500 meters from the towers, and we detect no discernible impact on the spectra from these directions. The one place we do see an impact is from the wind directions at US-INc, which are affected by the medical building located 50m from the tower, as previously discussed.

361. Figure 7. A communication tower located in the center of a complex roadway network is clearly not an appropriate site to mount an eddy covariance system. The photograph shows that the underlying surface is not reasonably uniform. In each sector, there are a myriad of buildings with different morphologies, as well as roadways with various characteristics and traffic.

We have shown this site to be quite valuable in existing literature (e.g., Kenion et al., 2024) and in publications in preparation.

368. Figure 8. This site provides an excellent example of where not to install an eddy covariance flux system. First, the system should not be affected by a major emission source, such as the freeway within 150 m of the tower. Second, the distribution of emission sources and sinks varies in all directions. For example, in the west sector, the eddy covariance system collects fluxes from a densely forested area, then from a neighborhood surrounding a lake, and finally from another neighborhood with a different topology.

See our note about US-INc. In addition to the work of Kenion et al. (2024), this site provided valuable measurements in the work of Vogel et al. (2024).

375. Figure 9. It's unclear what kind of fluxes this tower is supposed to characterize. Looking at the east sector, for example, it appears to include contributions from a warehouse, a parking lot, and a lake.

See the highly successful work decomposing biological and anthropogenic fluxes and comparison to the Hestia inventory model (Wu et al., 2022). In addition to providing the first-ever high-resolution (in space and time) comparison to Hestia, Wu et al. (2022) revealed the presence of winter photosynthesis, which has since been confirmed with our turfgrass flux measurements and modeling (Horne et al., 2025).

389-390. This is not feasible. It is only possible if two or three sectors contain relatively well-distributed emission sources and sinks across their entire footprint. When a sector is divided by many large areas with varied land uses, this is not possible.

We acknowledge the reviewers' comments and concerns regarding data interpretation and refer them to the data, as illustrated in Figure 8 (previous Figure 10). This clearly demonstrates a distinct CO_2 flux signal when a simple east-west separation is used, illustrating the power of simple wind direction separation in interpreting data from these complex, mixed urban flux towers. We also highlight the analyses of Vogel et al. (2024), Kenion et al. (2024), and Wu et al. (2022), which yielded highly interpretable results as a function of wind direction. We note that in each manuscript, we used flux footprint matching for more precise model-data syntheses; however, the outcomes support our argument that the data can be interpreted in a very useful fashion simply by considering wind direction.

400-402. There is no flux footprint model for urban settings; thus, they must be used to get a sense of the source area observed by the eddy covariance flux tower.

No footprint model is absolutely correct in any setting – there is nothing unique about the urban environment in this respect. We agree that the models should be used with caution. We have demonstrated that the Kljun et al. model, although an approximation, is quite useful in this setting, as shown in the work of Kenion et al. (2024), Vogel et al. (2024), and Wu et al. (2022). We clearly acknowledge the approximate nature of the flux footprint model, especially in this heterogeneous setting.

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Reviewer 2's Comments

General Comments:

The manuscript presents eddy covariance (EC) measurements collected as part of the long-term and ongoing Indianapolis Flux Experiment (INFLUX), which aims to investigate the exchange of CO_2, H_2O, energy, and momentum fluxes in and around the city of Indianapolis. The INFLUX EC network encompasses more than a decade and a half of observational site-years across a range of surface landscapes, making it, to my knowledge, one of the few initiatives to operate a large number of EC towers over such an extended time period in an urban context.

While interpreting EC data in urban environments poses significant challenges—primarily due to surface heterogeneity, which often violates the foundational assumptions of the EC technique—and despite ongoing debate about the applicability of post-processing procedures (e.g., spectral corrections, steady-state tests, and integral turbulence characteristics) originally developed for ecosystem sites, the dataset introduced in this manuscript offers unique and valuable insights into land-atmosphere interactions and greenhouse gas emissions in urban and peri-urban areas.

Given the scientific merit, the long-term nature of the dataset, and its potential for future research, I find this manuscript well-suited for publication in Earth System Science Data (ESSD), and I believe the dataset represents a meaningful contribution to the community.

We thank the reviewer for their openness to our effort to document new research approaches. We note for clarity that no foundational assumptions of the EC measurement have been violated. It is the typical assumptions used to interpret EC measurements that must be treated with caution. We have worked to clarify this point in the text.

Restating Specific Comments with Author Responses:

1. It would be helpful if the authors could provide a brief overview of the general climate characteristics of the Indianapolis region, including seasonal variations in air temperature, radiation, and precipitation. This contextual information would aid in interpreting the flux measurements and understanding the environmental background of the study.

   We agree with the reviewer's suggestion and have included a brief paragraph that provides annual statistics on precipitation and temperatures for Indianapolis, IN, USA. Please see section 2.1.

2. **Table 1.** Consider including additional key metadata parameters in Table 1, such as canopy height, roughness length, and displacement height. These variables are

relevant for interpreting the EC fluxes and would enhance the utility of the dataset. Furthermore, it would be useful to incorporate the landscape categories described in Lines 124–126 directly into the table for easier reference.

We thank the reviewer for their helpful comment regarding additional metadata. We have now included landscape categories in Table 1. We have also tried to include variables such as canopy height for the three mixed urban flux towers in Table 4. For the short-stature agriculture and turfgrass towers, we have not included variables like canopy height, displacement height, or roughness length because they are either on the order of centimeters for the two turfgrass sites or change throughout the deployment at the agricultural sites. Instead, we leave the determination of key parameters, such as roughness length and displacement height, to the individual user via anemometric methods. At the taller heterogeneous urban flux towers, we have included, with caution, single estimates of roughness length and displacement height in Table 4. We note in the text that these approximate values, while useful, should be treated with caution.

3. **Table 2.** The table indicates that ambient temperature and humidity are not measured at three urban sites. Could the authors clarify why these variables are missing? Additionally, if these data are unavailable, how are the sonic temperature normalization (SND) and Webb-Pearman-Leuning (WPL) corrections handled at these sites?

   We have added a discussion in section 2.3 articulating that this is done using an iterative approach employed by EddyPro, where only the sonic and gas analyzer measurements are used for the correction. The process is done in an iterative fashion. Resource limitations dictated the instrumentation that we chose to deploy on the towers.

4. **Table 3.** Please specify the threshold value(s) used for friction velocity. Is a uniform or site-specific threshold?

   We have included the site-specific friction velocity threshold in the metadata for each site.

5. **Lines 179–180.** The statement regarding data processing for the US-INf site could be clarified. Do the authors mean that despiking, WPL correction, and spectral corrections were not applied at this site? If so, what is the rationale for excluding these standard procedures?

   Unfortunately, we were unable to use uniform methods at this site. The instruments were deployed years earlier than US-INc and US-INg. Despiking was applied, but no *spectral corrections were made. High frequency spectral corrections for fluxes tens of meters above the surface are minimal (Berger et al, 2001).*

6. **Lines 252–254.** The authors mention that flux data were removed due to a masking effect, but only for momentum flux. Could the authors elaborate on why this masking correction was applied exclusively to momentum flux, and not to other fluxes?

   We thank the reviewer for their comment and have provided additional clarification in the manuscript. We acknowledge that the distortion from the tower likely has some impact on the scalar fluxes from the wind directions affected by this distortion. We do not detect, however, any impact of the distortion on scalar fluxes at our towers, and thus leave the decision to remove up to the individual data user.