Manuscript Number: AMT-2023-253

Manuscript Title: Role of time-averaging of eddy-covariance fluxes on water use efficiency dynamics of Maize crop.

AUTHORS' RESPONSES TO REVIEWER – 2 COMMENTS

The authors have carefully considered the reviewer's comments and the manuscript has significantly improved. I suggest to pay attention on the few comments below, in particular the comment 7.

- Thanks to the reviewer for valuable comments and appreciation.
- We have addressed all the comments and provided our responses in a detailed manner.

General comments

Detailed comments

1. 1. L. 16-17. The canopy heat storage is not the only reason for the departure of the EBR from unity. The current study was investigating the impact of low-frequency flux loss as one of the reasons; there are also potential other reasons such as impact of advection and others. In general, the incomplete energy balance closure is a well known problem (as acknowledged also by the authors in the manuscript) and is not definitely uniquely attributed to the heat storage.

- Agreed that, apart from canopy heat storage, there a few other possible reasons for departure of EBR from unity as listed below:
    - i) Ignoring canopy heat storage terms
    - ii) Advection due to movement of water (evaporation, rainfall, etc.) through the atmosphere in the ecosystem.
    - iii) Low-frequency circulations (large eddies) losses
    - iv) Inadequate time-averaging techniques
    - v) Improper selection of suitable measuring locations in heterogeneous flows
    - vi) Instrumentation and systematic errors
- In this study, we ensured that the instrumentation and systematic errors are negligible and measurements are performed in homogeneous croplands. So, we omitted these factors responsible for EBR departure.
- Regarding advection, we segregated the data into advection ($H < 0$ and $LE > 0$) and non-advection ($H > 0$ and $LE < 0$) components, and obtained a weaker correlation

between temperature and relative humidity. Hence, we conclude that advection is not a major source for EBR departure (Rahman et al., 2019). This is also due to the fact that, the study site is not surrounded by water reservoirs or other sources.

- Hence, we only investigated the other major sources like canopy heat storage, low frequency flux loss, inadequate time-averages on EBC closure in this study.
- However, to give more clarity, we modified the given statement in the revised manuscript as follows (Line: 16 to 18):

"A clear departure of EBR from unity was observed during dough and maturity stages of the crop due to ignorance of canopy heat storage, low frequency flux losses and inadequate averaging period".

2. L. 22, the reported values of the WUE during different periods are defined by the average number +- variation range. It is not self-explaining what these values after +- mean. I raised the same question earlier in the first revision in relation to reported climatic average temperatures (section 2.1). The authors responded that it is a common practice in statistics to represent the mean +- standard deviation. I argue that it is not uniquely clear: it is a common practice to represent experimental results mean+-error, which frequently means the standard error of the mean. Or, it could be also the confidence intervals of the mean at some significance level. Therefore, to be clear, I always prefer that it is specified what variation range is presented.

- We sincerely apologize for the confusion created in this regard.
- When representing the variation in data series, we use $\mu \pm \sigma$ (mean ± standard deviation), as this explains the most of the data variation.
- When conveying the precision of the sample mean, we use $\mu \pm SE$ (mean ± standard error), as this provides an estimate of the population mean.
- It should be noted that, both SD and SE are inter-related. $SE = \frac{SD}{\sqrt{n}}$
- However, to avoid further confusion:
    1. We used $\mu \pm \sigma$ when denoting data range / dispersion in a given series
    2. We used mean (μ) alone, when representing the central tendency of data series
    3. When used for the first time, we clearly expanded the terms, μ (or) $\mu \pm \sigma$ in the revision

3. L. 135, presumably the +- values represent here the inter-annual variability (standard deviation) of the summer and winter seasons mean temperatures over a range of years. Again, it is not self-explaining. Also, the +- values do not provide here additional information and could be omitted.

- Again, sorry for any confusion.
- We have specified the terms μ and σ (line: 135) to avoid confusion.
- SD represented here (± 2 ^{o}C) gives an indication that, most of the data (high and low temperatures) is concentrated around the mean, and the variability is low.

4. L. 168 and the averaging periods: it was explained that the co-ordinate rotation was performed over the same time interval as the averaging period. Presumably 1 minute is in general too short time period to define a "stable" co-ordinate system. The authors should admit that such a short averaging period introduces significant random uncertainty due also due to co-ordinate rotation bound to the same period.

- Agree with the reviewer that 1 min is too short to define stable co-ordinate rotation, hence introduces additional random uncertainty.
- We also obtained similar results, as 1 min time averaged data has a large scatter (randomness) which is evident from the inset of Figure 1.
- We incorporated the referee's suggestion in the revised manuscript (line: 292 to 296) as follows:

"The variation is rough at lower averaging periods due to a high sample size (n = 10859 at T = 1 min) and is gradually smoothened towards higher averaging periods (n = 811 at T = 120 min). The shorter averaging periods has introduced random uncertainty in the datasets during co-ordinate rotation correction."

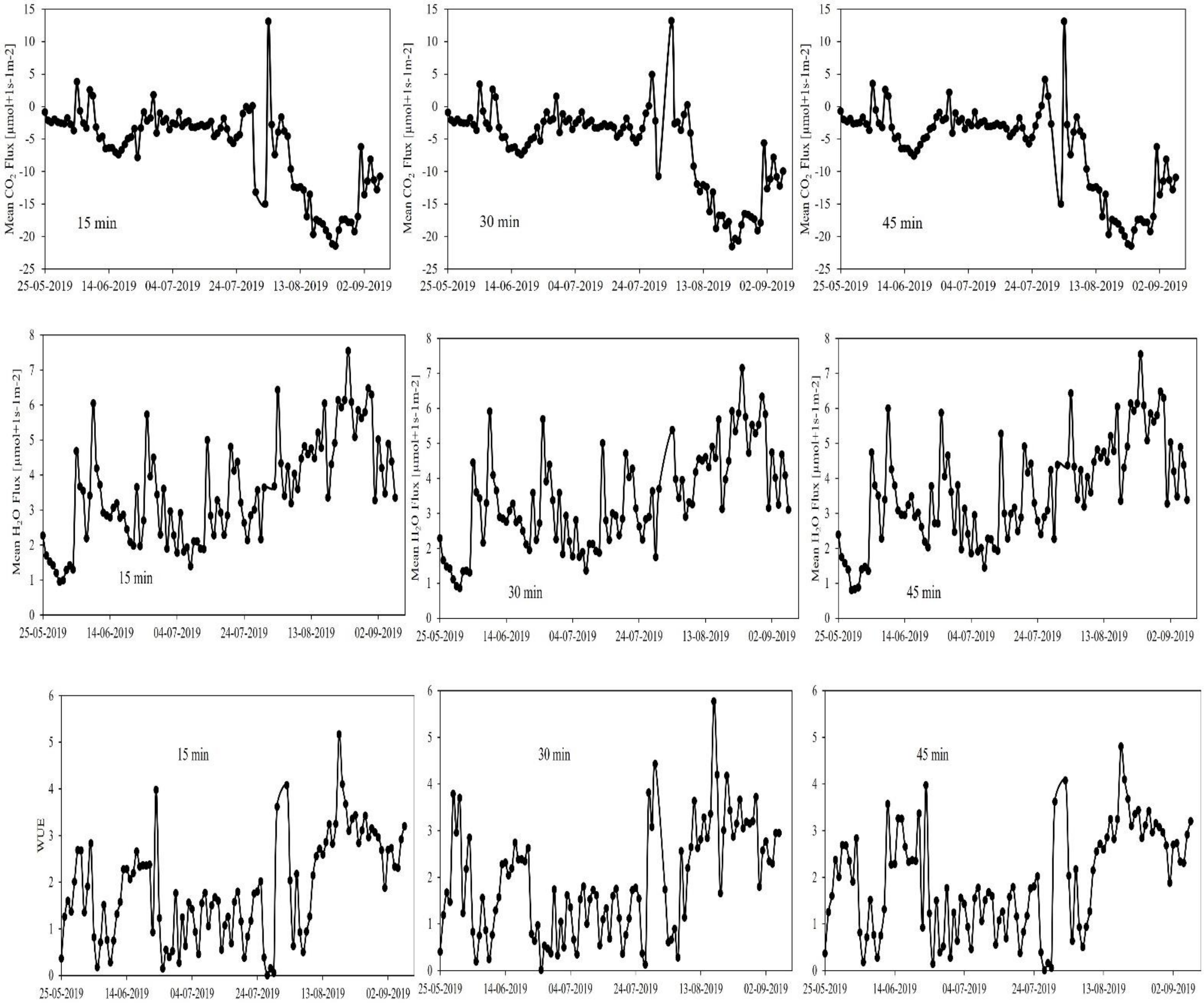
5. L. 326-328, the sentence is difficult to understand. Could it be something like "We did not observe variation of optimal averaging time with wind speed and direction, hence".

- Agreed. This sentence is modified in the revised manuscript (line: 329 to 330) as follows:

"We did not observe variations in optimal averaging time due to changes in wind speed and direction, hence meteorological conditions were not analysed in this study."

6. Fig. 8: Please specify in the figure title that the circle size represents the correlation magnitude. And the colour scale the sign? Did you observe also negative correlations? If not, it would be more clear to represent the colour scale from 0 to 1. If there are negative correlations on the average, then how do you interpret those?

- Agree with the reviewer, and accordingly revised the figure title.
- Yes, we observed a negative correlation only with WUE, but not with CO_2 or H_2O fluxes (Figure 8c).
- Negative correlations are mainly due to the inverse relations between two datasets, as CO_2 acts as either sink (daytime) or source (night-time), and H_2O fluxes always acts as source. WUE, being the ration between the two fluxes has resulted in either positive or negative variations considering different averaging periods.
- For ease with understanding, the dynamics of carbon (top row), water (middle row) and WUE (bottom row) for 3 averaging periods (15-, 30-, 1md 45-min) are given below.



- Observe similarities in carbon (or) water fluxes between different averaging periods, as well as dissimilarities in WUE fluxes between different averaging periods. This has resulted in all-together a different set of correlations.
- Additionally Figure 8c is not plotted as per crop growth stages, hence stage-wise variations were not included in the final values.

7. L. 448-450: if I understand the fig 8c correctly, then it is not true that a poor correlation was observed between any two averaging periods. The correlation between the periods 15 min and 45 mins looks close to 1. Also, the correlation between 1 min and 30 min averaging is fairly high. It is natural that the correlation of WUE (which is the ratio of the two fluxes with both having their random uncertainty) values for different averaging periods is lower. However, it is counter intuitive that the correlation between 15 min and 45 min averaging periods is high, but for 15 mins vs 30 mins (which are more close averaging periods) is completely lost. If such behaviour results from uncertainty in single WUE values (or possibly correlations being impacted by "outliers"), then Fig. 8c does not serve as useful information providing insights into WUE dynamics and should be omitted.

- This is mainly due to the behaviour of fluxes at different averaging periods. The above figure presents the dynamics of carbon, water, and WUE fluxes at 15-, 30-, and 45-min averaging periods.
- A close inspection of these figures concludes that:
    - Variation in carbon and water fluxes is similar (both trend and magnitude) among all three averaging periods. Hence, we achieved high correlation with carbon (Figure 8a) and water (Figure 8b) fluxes between any two averaging periods.
    - However, variation in WUE fluxes is similar in magnitude between 15- and 45-minute averaging periods only, but not between 15- and 30-minute averaging periods.
    - While we could not certainly ascertain the reasons, this conclude that conventional 30-min averaging may not be appropriate throughout the growth period in representing the WUE fluxes.

- With this, we think that the Figure 8c provides an important insights and information on WUE dynamics at different time averages.

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AUTHORS' RESPONSES TO REVIEWER – 3 COMMENTS

Most of my questions were answered by the authors in the first round of reviews. However, I have some suggestions and minor corrections that can improve the manuscript.

- Thanks to the reviewer for providing valuable suggestions and comments.
- We have addressed all of your comments in a detailed manner.

I - General comments:

1) Beside the main objective of obtaining the optimal averaging time period, the authors also evaluated CO_2 and water vapor fluxes for the different growth stages. I think this result is also relevant. There is no discussion relating the average flux intensity to the growth stages (figures 3a and 3b). Are these observed flux differences in different growth stages spected? Are there studies showing similar results that can be cited? This discussion can be included in the present manuscript if the authors deem it relevant.

- We observed that averaging period has little to no influence on mean carbon and water fluxes, averaged over each growth stage. This is particularly true with 6th leaf and silking stages. However, maturity and dough stages are exceptional, particularly with 45-min averaging period.
- Variation in flux intensity with growth stage is mentioned in lines: 344 to 346 of the revision.
- Following reviewer suggestion, averaging flux intensity variation with growth period is provided in the revision (lines: 346 to 352) along with a discussion and literature support.

"From the mean CO_2 and H_2O flux dynamics, it is observed that the drip irrigated Maize crop is acting as a carbon sink in the entire crop season especially in the latter stages of the crop i.e. maturity stage with a mean of 15.44 μmol $m^{-2}s^{-1}$. This is clearly evident from the increasing trend of LAI and plant height during the crop season. Such an increase is highlighted by previous studies of Guo et al., 2021. At the same time, mean H_2O fluxes were increased towards the end of crop growing season due to increased crop water demand."

2) Line 316: "particularly with dough and maturity stages due to ignorance of canopy heat storage." and line 322: "Low EBR during the crop cycle can also be attributed to the ignorance of energy transport associated with large eddies from landscape heterogeneity.". The authors must cite studies that support those hypotheses.

- Agree with the reviewer, and we have added the citations that support our hypothesis about the low EBR (line: 327 of revision).

II- Specific comments:

1) Line 120: "…compute optimal averaging period to simulate carbon and water (hence, WUE) fluxes of Maize crop,". In my understanding, "to simulate" should be changed to "to evaluate" or "to calculate". No simulation is mentioned in the manuscript.

- Agreed, and changed as below:
  "Identify optimal averaging period to evaluate carbon and water (hence, WUE) fluxes of Maize crop."

2) Check equation 10 (R^2): The current equation provides a dimensional parameter.

- It's a typo. The equation is modified in the revised manuscript as follows:

$$R^2 = \left\{ \frac{\sum_{i=1}^{n}\left[(R_n - G)_i - \overline{(R_n - G)}\right]\left[(H + LE)_i - \overline{(H + LE)}\right]}{\sqrt{\sum\left[(R_n - G)_i - \overline{(R_n - G)}\right]^2\left[(H + LE)_i - \overline{(H + LE)}\right]^2}} \right\}^2$$

3) Figure 1 (and throughout the manuscript): you should use a standard abreviation to the minute unit ("min" not "Min").

- We have changed the abbreviation for minute in the Figure 1 and we followed a standard abbreviation of "min" for representing the minute unit in throughout the manuscript.

4) Figure 8). Caption referes to subplots a, b and c, but those identificantion are not shown in the figure.

- Sorry, we have provided the identifications for the subplots in Figure 8 in the revised manuscript.

5) As I understood, the correlation chart shows the correlation evaluated using the series of daily averaged fluxes calculated using different average windows. Am I right? The methodology used to evaluate these correlations should be clarified in the manuscript.

- Sorry to the reviewer for any confusion.
- Yes, the correlation chart shows the correlation evaluated using the series of daily averaged fluxes calculated using different average windows.
- We modified the given sentence in the revised manuscript (line: 449 to 450) as follows:

"Correlation charts showing the linear association considering daily means of carbon, water, and WUE fluxes at different averaging periods is represented in Figure 8."

6) Line 448: What is the parameter rho (ρ)? It is not defined in the text. Is it associated with the R^2 or the r parameter?

- Sorry to the reviewer for the confusion.
- This is associated with the parameter "r" and the is modified in the revised manuscript.