Reply to Referee #2

Firstly, we would like to thank the Referee for a useful review that we believe can help us improve the manuscript significantly. Following are replies to the Referee's comments.

Comment 1:
The opening of introductory section was too abbreviated. Recommend additional description/background of the EC method including additional references. The definition of synchronicity could be improved. For example, an EC system with a fixed, known lag would be considered asynchronous by this definition but not one that leads to flux error in the context of this manuscript

We agree and are now extending the introduction with a richer description of the Eddy Covariance method, and reviewing the definition of synchronicity. We would like to note, however, that - for the sake of completeness - we did intend to include time lags among the misalignments, only to later ignore it because it is a *correctable* misalignment. For this reason, the revised definition of "synchronous" would still not include an EC system with a (fixed) time lag.

Comment 2:
The manuscript has no explicit discussion of data triggering for digital data acquisition. This reviewer interpreted that all descriptions of digital data communications referred to streaming data. A brief discussion of triggering for data acquisition should be included in the Introduction, particularly as it relates to synchronizing data streams and timing errors.

The Referee correctly interpreted that the paper is concerned with systems based on streamed data. As suggested, we added a brief discussion of systems based on data triggering and clarified that we concentrate on streaming-based systems. The reason for this choice is that implementing a triggering-based system is much more complicated to the non-specialist and it is very often just not allowed by the instruments. For example, to the best of our knowledge most sonic anemometers and gas analysers (also beyond CO_2 and H_2O) do not support a triggering signal, while all instruments we are aware of do provide data in streaming mode.

Comment 3:
The manuscript (section 1.2) describes open digital communication protocols including serial and Ethernet (packet-based) but do not address SDM (Synchronous Device for Measurements) communications. SDM is a very commonly used data communication protocol for collecting EC measurements and eliminates many of the timing errors described in the manuscript through clock synchronization. The authors should include a discussion of this protocol and which timing errors are applicable

SDM does not "synchronize clocks", but rather implements a triggering strategy to avoid STEs (while still being subject to potential RTEs). It is therefore an instance of a system based on triggering signals, that will be discussed in the new version of the manuscript as described above. We will also briefly reference the SDM protocol, which, however, is a Campbell Scientific Inc. proprietary protocol, implemented in a small number of instruments (manufactured by only LI-COR Biosciences and Campbell Scientific) and very unlikely to ever be implemented in new instrumentation, other than Campbell's. We have designed our manuscript without explicit reference to specific commercial solutions (including SmartFlux™, released by LI-COR Biosciences) and we therefore intend to only add a note on SDM, without entering in any details.

Comment 4:
Considerable differences in flux errors (1 vs. 11%) were found between two sites given the same STE (180 μs/s). The explanation given was differences in the flux contribution in the frequency domain (cospectrum, see Figure 7) which is reasonable given the differences in observation height. In Fig 7, the cutoff frequency (transfer function) appears to differ between these two sites. However, in the text and as shown in Figure 6, the authors state that the transfer functions across sites were similar. Could this discrepancy be clarified?

While we agree with the Referee and have been puzzled as well by the visually perceived difference between the two transfer functions implied in Fig. 7, we came to believe that the plot correctly shows the effect of the *same* transfer function on two cospectra with very different shapes. In the reply to Comment 6 (see later) we propose a new Figure that makes use of model cospectra, to provide more details about how and when STEs generate significant errors in the form of spectral losses. In that Figure, the same visual effect of Fig. 7 can be seen: compare, for example, plots (c) and (f). We do suggest to replace current Figure 7 with the figure below, which allows more elaborate discussion.

Comment 5:
One the main points made in the manuscript is that timing errors cannot be corrected or detected a posteriori. Given that the authors frame timing errors in the context of a low pass filter, it seems reasonable (assuming of spectral similarity between w'T' and w'c') that timing errors would be accounted for and corrected by spectral correction methods that consider cospectra shape. Of course, such an approach could not differentiate between the source of signal loss (timing error, inlet tube attenuation, sensor separation, etc). The proposed approach assumes no timing error in the w'T' which is reasonable if calculated from a single SAT

We agree with the Referee that, in principle, an *in-situ* spectral correction method based on co-spectra would indeed correct timing errors as well. One caveat is that, in our opinion, spectral attenuations in the gas analyzer are better assessed using solely gas spectra rather than co-spectra (for the reasons put forward in [1]). It also appears to us that addressing the different sources of spectral losses individually allows for more control and fine-tuning of the correction.

We will modify the discussion to better clarify this point and suggest that, at least in principle, a spectral correction based on cospectra would indeed correct for STEs. That said, we would also stress that one should always strive to avoid eliminable sources of bias errors, and STEs/RTEs fall in this category.

Comment 6:
The manuscript would be strengthened if the findings were placed in the context of other sources of EC errors and uncertainties, particularly for fluxes of gas species. For example, one could apply the timing-error transfer function to the gas cospectra in concert with transfer functions of other spectral loses to illustrate relative contributions

In the original manuscript (Pag. 8, Lines 22-27) we tried to put STE-induced errors in perspective by comparing the corresponding cut-off frequencies with those found in literature for modern CO_2/H_2O EC systems. In general, we think that discussion of spectral losses of any given EC system should be limited to transfer functions and cut-off frequencies, because these are properties of the system itself, regardless of its deployment. Actual flux errors and relative contribution of different sources of spectral losses, as well as the other sources of uncertainty and error, depend critically on measurement height, turbulence regime and site characteristics.

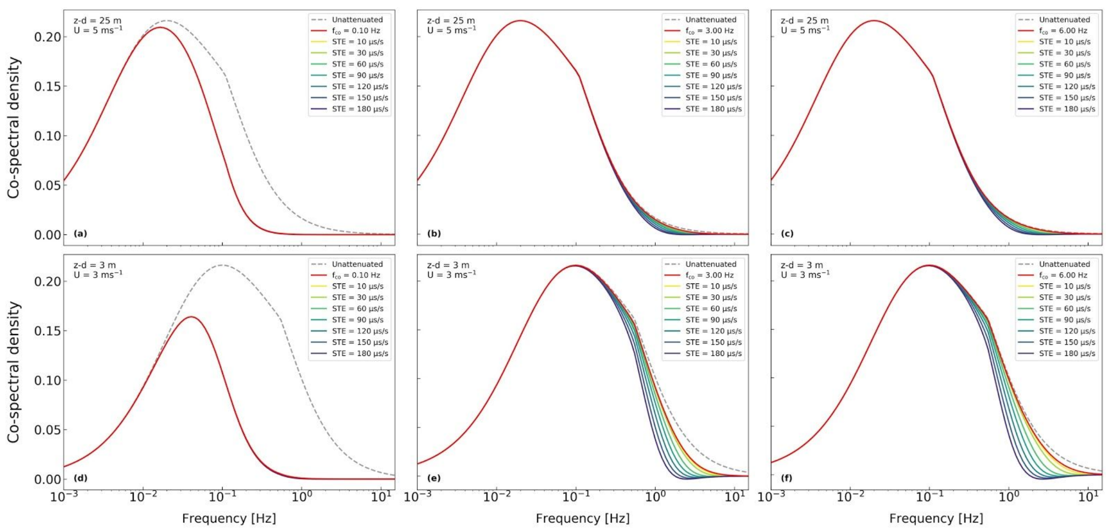

Figure AC1. Effect of adding different STE to 2 EC systems characterized by different cut-off frequencies (left to right) and by different measurement height and mean wind speed (top to bottom). It is evidenced that: at high measurement heights effects are negligible irrespective of the "original" cut-off frequency of the system (a-c); at low measurement height, STEs significantly increase spectral losses if the system has a high "original" cut-off frequency (e-f). If the system as a poor spectral response to start with, STEs are irrelevant (d).

Nonetheless, following the suggestion of the Referee, we prepared Figure AC1, which could be added to the discussion for a quantitative, hopefully more intuitive, understanding of the errors potentially caused by STEs. Further, we suggest that Figure AC1 could replace current Figure 7, as explained above (see reply to Comment 4).
The figure shows how different STEs would affect the overall transfer function of a given EC system affected by other sources of spectral losses.

Technical Corrections:
In the revised manuscript, we will accept and implement all minor editing suggestions of the Referee.

References

[1] Ibrom, A., Dellwik, E., Flyvbjerg, H., Jensen, N.O., Pilegaard, K., 2007. Strong low-pass filtering effects on water vapour flux measurements with closed-path eddy correlation systems. Agric. For. Meterol. 147, 140–156.