Biogeosciences Discuss.,
https://doi.org/10.5194/bg-2018-177-SC1, 2018

Interactive comment on "Eddy Covariance flux errors due to random and systematic timing errors during data acquisition" *by* Gerardo Fratini et al.

W. Eugster

werner.eugster@usys.ethz.ch

Received and published: 29 May 2018

The authors correctly refer to Eugster and Plüss (2010) where we argued that old-style traditional eddy covariance data acquisition systems used a combination of analog and digital data transmission. What the authors did not correctly reference is the fact that the Eugster and Plüss (2010) paper actually presents a high-quality fully digital data acquisition system and thus I am in disagreement with the authors in virtually all aspects of their manuscript. Fig. 1 below is a modified version of Fig. 1 in Eugster and Plüss (2010) showing the ideal fully digital acquisition system as Fig. 1c – this is what Eugster and Plüss (2010) recommend. The authors of this manuscript however try to put forward a downgrading of data quality that corresponds with Fig. 1b below. Although it is the authors freedom to have an opinion on this, their problems with their

sites cannot be generalised to other sites and namely their examples are not at all convincing me that downgrading a data acquisition which is using digital instruments to analog data transfer is yielding better flux results than keeping the digital data in digital format with as little loss as possible as suggested by Eugster and Plüss (2010).

On page 2, line 9 the authors of this manuscript write "Analog data output allows the data to easily cross clock domains. The clock that is used to sample the original signal does not need to be synchronized to the clock that samples the analog output. This makes it very convenient to merge data from systems with unsynchronized clocks." What they completely ignore is the fact that digital-to-analog conversion normally involves some stabilising R-C electronics (antialiasing) filter that dampens the original signal, and at the same time an analog-to-digital conversion is also equipped with a low-pass filter to avoid aliasing effects. Contrastingly, a fully digital data acquisition system of the kind proposed and used by Eugster and Plüss (2010) benefits from the same aspect claimed to be a quality of analog data acquisition: that only one clock is used for producing high-quality datasets. The concept used by Eugster and Plüss (2010) is to use the most reliable clock – that of the data acquisition computer that can be drift corrected with standard methods (in case Linux is used as an operating system, this can be achieved e.g. via the `/etc/adjtime` settings) or using some reliable time protocol services.

It is incorrect to say that "moving between clock domains is trivially simple in an analog system, it is much more challenging with digital data" (page 2, lines 31–32); this argumentation is simply ignoring that the authors use a one-clock system to collect data in the same way as Eugster and Plüss (2010) do it with a digital system, whereas analog input is treated clockless. It however reflects the authors personal skills to actually do this. For me it is as trivial to do digital synchronisation as these authors do analog synchronisation, but this has nothing to do with science but with personal experience; I have done it since 20 years, and hence I have full understanding that others find it less trivial.

On scientific grounds its however as trivial: with both analog and digital synchronisation you always want to merge the most recent measurement of one instrument with the most recent measurement of the other one. That's also the concept presented by Eugster and Plüss (2010): whenever a data record of the ultrasonic anemometer is received the most recent measurement of a gas analyser or fog droplet spectrometer available in the data queue is merged with the sonic anemometer data. But this is done in a fully digital mode (Fig. 1c), which means: the resulting dataset has the best possible date and time information of the Linux data acquisition system, uses the regular spacing of the reliable sonic anemometer (which has numbered records and thus any loss of data would be detected in a digital datastream), and at the same time each sonic record has the most recent information received from any additional analyser sending data in digital mode. The authors claim they have a better system but ignore that the only reason why an analog signal is present at any time at their analog input is because of some electronic (R-C) buffer that applies some degree of smoothing to that signal (which makes an analog signal valid over a longer timespan than a digital signal). With fully digital data acquisition of the type proposed by Eugster and Plüss (2010) (Fig. 1c) some rules have to be followed to avoid gaps in the data. Following the concept of analog data we suggest to simply repeat the previous record in case that no new one arrived from a gas analyser whenever the next (numbered) sonic record is received. Here, I would agree that improvements are possible since instruments have appeared on the market that use package-based non-realtime digital data transfer (TCP instead of UDP protocols, for example). The effect is, that if the data from the attached analyser are apparently arriving at a lower data rate than the nominal (and stable) data rate of the sonic anemometer, and if only the most recent arriving data record is retained and merged with sonic data. The potential effects of such problems was presented and discussed in quite some detail by Eugster and Plüss (2010). As a short summary: the effect on fluxes is small and well below empirical uncertainty of eddy covariance flux measurements (typically $\pm$10–20%), but there is some damping introduced that needs to be corrected for. This is however also the case for a digital–analog–digital system

(Fig. 1b) due to the lowpass antialiasing filters used in the signal conversion in both directions (as depicted with "noise" in Fig. 1), and modern eddy covariance data processing software is capable of correcting such high-frequency damping losses. There is thus no scientific reason to believe that converting a digital signal to an analog one and then back again (Fig. 1b) will achieve better results than simply using the digital signal which can be processed without losses.

It is of course not impossible to generate a mismatch in timing that can lead to an underestimate in fluxes of up to 10% (page 2, line 14), but the authors forgot to mention that this is part of the high-frequency damping (see e.g. Eugster and Senn (1995)) that is corrected for in state-of-the-art systems. In Eugster and Plüss (2010) we have presented results how a mismatch of sampling frequencies of the sonic anemometer (running at nominally 20 Hz) and another analyser delivering data at 1/2 (10 Hz), 1/5 (4 Hz), or 1/15 (1.3 Hz) affect variances and fluxes. It is very clear that the better the data acquisition the lower this high-frequency loss correction, but that aspect is completely unrelated to the question whether analog or digital data acquisition is chosen, as long as we can agree that it is better to use one single clock (we use that of the Linux computer corrected for long-term drift) in combination with the very stable, continuous and lossfree data collection from the sonic anemometer (record numbers make sure this is lossless).

In their Fig. 9 the authors show that their clock has a drift of 12 seconds over 70 hours. This means, that their clock has a drift of 0.004762% – a ridiculously low value compared to the uncertainties of the single measurements performed by any sonic anemometer or gas analyser. In practice this means that if their drift means that the clock is too fast, then a system collecting at nominally 20.0 Hz is collecting at 20.00095 Hz, or if it is a slow clock this is 19.99905 Hz. Now, if we translate this effect to the accuracy of the flux, we add a scaling factor α to the nominal frequency f expected from an eddy flux data acquisition system. The reference flux with $\alpha = 1.0$ is

$$\overline{w'c'}_{ref} = \int_0^\infty Co_{w,c}(f)df \; . \tag{1}$$

If frequency f is slightly off by a factor $\alpha \approx 1.0$, then

$$\overline{w'c'}_{\alpha} = \int_0^\infty Co_{w,c}(\alpha f)d(\alpha f) \tag{2}$$

$$= \alpha \int_0^\infty Co_{w,c}(\alpha f)df \tag{3}$$

$$= \beta \, \overline{w'c'}_{ref} \; . \tag{4}$$

This means that the flux is enlarged by a factor $\beta \ll \alpha$. In Fig. 2 I simulated this effect using the parameterisation for normalised cospectra under neutral and instable conditions (Eq. 26 in Eugster and Senn (1995)). Thus, the flux – if only the drift of the main clock is of relevance – has to be multiplied with a factor β that is much smaller than the drift. As a reading example: if α is unrealistically large with a value of 1.05 (i.e., 5% drift! See blue dashed lines in Fig. 2) then β is on the order of 1.00015. In other words: even if the clock drifts by 5% then the flux will only be off by 0.015%, everything else being held constant. The reason is of course obvious: a 30-minute period over which we average remains a 30-minute period, even after correction for drift.

Thus drift is not the issue in this case. If there is jittering of the incoming data, then this will lead to a damping. The effect of damping was well addressed by Horst (1997) and before that by Eugster and Senn (1995), thus corrections for this effect exist, parametrisations exist, and these are actually applied in modern eddy covariance software.

The example shown by the authors in Figure 7 first indicate that the IT-Ro2 site has serious issues already in the original data. A correctly calculated cospectrum only shows such a change from the inertial subrange towards a white noise slope at the highest frequencies if there are serious issues with the sensors and/or data acquisition that lead to correlated noise in w and c. If noise in w and c are uncorrelated as in a high quality data acquisition system (e.g. as presented by Eugster and Plüss (2010)), then such artefacts do not exist.

To illustrate this I downloaded some raw data collected yesterday (2018-05-28) by a high-quality ICOS Level 1 Candidate site (CH-DAV) that uses a data acquisition system of the type suggested by Eugster and Plüss (2010) (Fig. 1c). I used two hours of data from 13:30 to 15:30 CET and produced cospectra of the sensible heat flux (Fig. 3a) and the CO_2 flux (Fig. 3b). Neither of these shows any signs of white noise in the high frequencies. I chose a log-linear display since this is the only depiction that gives an optic representation of artefacts that is proportional to the area below the cospectrum. Thus, visually the integral under the bold curve is 1.0 (normalised cospectra), and any fraction of area at one frequency is the same size at another frequency. The blue dashed lines overlain over the cospectra are idealised undamped cospectra (see Eugster and Senn (1995) for equations and more details).

My experience as a reviewer is that often “cospectra” of the kind shown for IT-Ro2 in Fig. 7 are simply due to erroneous calculations of the cospectrum. I cannot double-check this hypothesis with the IT-Ro4 data shown at right in Fig. 7 since the authors hide the relevant part of the data at high frequencies in both panels, a bad practice irrespective of disagreements between the reader and the authors. Moreover, cospectra have both positive and negative cospectral densities (see my Fig. 3). If authors only show positive values it is unclear on wheather (a) they use the wrong calculation method, or (b) they hide negative values, or (c) they took the absolute values of the cospectral density. The method we used in Eugster and Plüss (2010) follows a concept that I learned from Ivan Mammarella, where different symbols are used for positive and negative cospectral densities, and the absolute value is depicted. With such a display the scientific correctness is still fullfilled, whereas this manuscript suffers severely in all aspects.

Why did the authors not submit this to Atmospheric Measurement Techniques where editors are listed that have a much deeper understanding of such technical topics? Overall, I do not believe that this is sound science, in my view it is a huge step backwards, ignoring existing best available knowledge to a frightening degree, and hence I would fully support the Editor in his decision to reject this manuscript without suggestion to submit it elsewhere.

References

Eugster, W. and P. Plüss (2010) A fault-tolerant eddy covariance system for measuring CH_4 fluxes. *Agric. Forest Meteorol.* **150**, 841–851.

Eugster, W. and W. Senn (1995) A cospectral correction model for measurement of turbulent NO_2 flux. *Boundary-Layer Meteorol.* **74** (4), 321–340.

Horst, T. W. (1997) A Simple Formula For Attenuation of Eddy Fluxes Measured With First-Order-Response Scalar Sensors. *Boundary-Layer Meteorol.* **82**, 219–233.

Interactive comment on Biogeosciences Discuss., https://doi.org/10.5194/bg-2018-177, 2018.

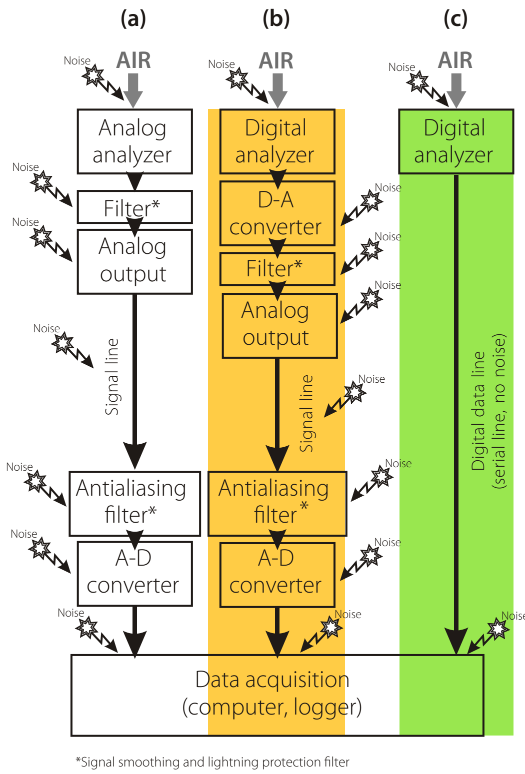

Fig. 1. Three variants of data acquisition systems. Modified after Eugster and Plüss (2010).

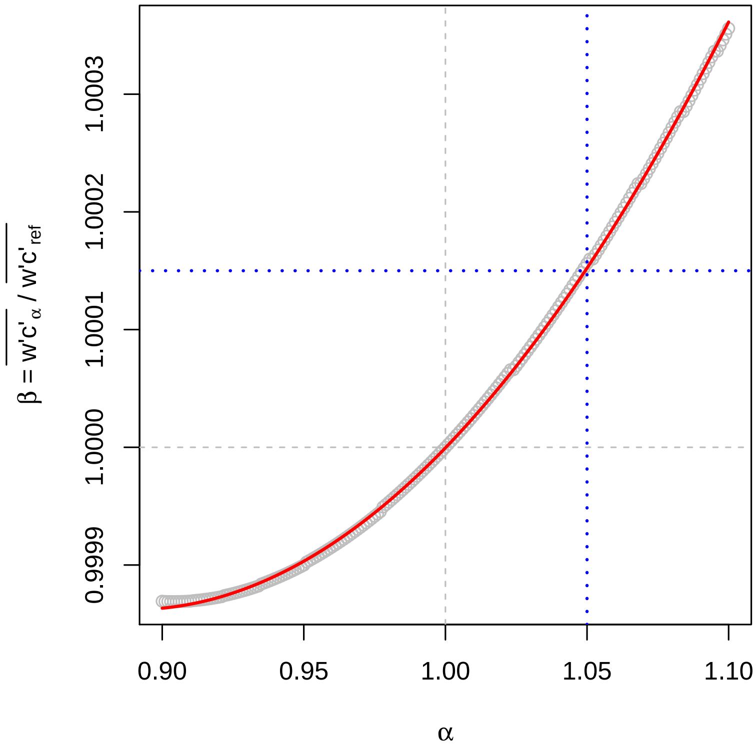

Fig. 2. The effect of a frequency that is off the nominal frequency by a factor α on the eddy flux.

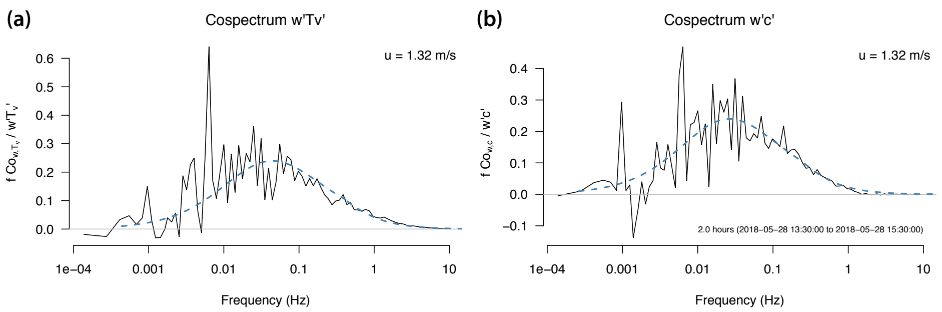

Fig. 3. Example of two cospectra yesterday (2018-05-28) at CH-DAV, an ICOS Level I Candidate Site.