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

I. Bogoev

ivan@campbellsci.com

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The paper draws the attention to an important topic in EC measurements sometimes inadvertently neglected by practitioners.

General comments:

The scope of the paper is too narrow and addresses only a certain class of eddy covariance (EC) systems with instruments providing data to the data logging system via Ethernet or serial communication protocols and does not mention an important digital communication protocol, called Synchronous Devices for Measurement (SDM) that has been in use for more than 18 years. This protocol was specifically developed to meet the stringent requirements for time synchronization between the EC sensors. Two

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Discussion paper

sensor manufacturers, Licor Inc. and Campbell Scientific, Inc. collaborated and implemented this protocol in some of their instruments. The SDM protocol allows for external instrument triggering at precise moment in time, so multiple sensors can be measured synchronously. Some sonic anemometers, like the CSAT3 (Campbell Scientific, Inc.) can accept a trigger and provide almost instantaneous measurement when prompted by the datalogger. This approach does not require the complexity of high level of clock synchronization between individual devices.

The authors should include more details about the fundamental principle of operation of the devices used in EC systems and more specifically the widely used NDIR analyzers and sonic anemometers. Both of these sensors require some finite amount of time to make and process each measurement. They cannot provide a continuous analog signal, but rather discrete measurements. Consequently, the analog voltage outputs provided through the digital to analog converters (DAC) are discrete in time and magnitude.

A unique feature, specific only to the gas analyzer, is the use of a rotating optical filter wheel to multiplex the desired infrared bands used in the gas concentration measurements. The gas analyzer can produce a single measurement of CO2 and H2O per each rotation of the filter wheel. This makes the frequency of the concentration measurements dependent on the rotational speed of the chopper wheel. If a precise timing is required the speed of the filter wheel need to be controlled precisely. Also, because of the dependency between the measurements and rotation of the wheel, the gas analyzer cannot be triggered to provide CO2 and H2O readings at a precise moment in time. So, the only option to provide a reading at a given moment in time is to spin the filter wheel fast (like 150 rotations per second for the Li-7500) and report the measurement made immediately on the next rotation of the filter wheel. With this approach the gas readings could be at best synchronized to 1/150 second (6.7 ms), which is proven acceptable for most EC applications.

Similar approach should be implemented with sonic anemometers that do not have a trigger mode and the ability to provide a measurement upon a request from the datalogging system.

A new generation of EC systems has been available for the last several years. These EC systems include a gas analyzer and a sonic anemometer, as co-located or as stand-alone devices, that share a common set of electronics so that wind, temperature and gas concentration measurements can be made simultaneously. This approach does not require precise clock synchronization and still provides sub millisecond timing between individual measurements.

The study examines only the errors in the co-variance of vertical wind and sonic temperature. The errors in the scalar fluxes could be strongly modulated by the density effects (WPL) associated with temperature and humidity. The scope of the paper can be extended to characterize the effect of timing errors on H2O and CO2 fluxes which are of most interest in energy and carbon balance studies. The ability of the IRGASON to provide synchronous temperature, wind, H2O and CO2 readings makes it a suitable instrument to study the reduction of co-variance not only on vertical wind and temperature, but on the other scalars. The implications of underestimated sensible heat flux due to systematic timing errors and its effects on the WPL terms and ultimately on the CO2 flux could be addressed.

Additional information about the data sets used in the study should be included, like sample rate, sensor path length and anti-aliasing filter bandwidth.

The validation of the simulation design is not convincing, because the experimental conditions for the 100 Hz sonic data are unknown. (Co)spectral plots should be shown to verify the spectral content of the validation signals. It would have been more appropriate to use 100 Hz data from one of the EC sites.

Specific comments:

Page 1, Line 10: Synchronizing the clocks of the individual devices is only important when the devices don't have a triggered mode.

Page 1, Lines 25-26: In the IRGASON the wind and the concentration data are made by the same instrument.

Page 1, Line 27 The separation between the sensors needs to be minimized. The requirement of the EC method is that the physical quantities are measured at the same point in space, so that co-variances are preserved

Page 2, Lines 9-10: Analog data output from a discrete sensor like a NDIR gas analyzer or a sonic anemometer can't cross clock domains. It can only be achieved, to some degree, if the measurement rate of the device is sufficiently high (above 100 Hz) and the digitization steps of analog signal becomes small.

Page 2, Line 21: raw measurements are not analog, but discrete, as was explained above.

Page 2, Line 25: Fully digital systems are not new. Sensors, like the CSAT3 and the Li7500 with SDM synchronous digital outputs, have been available for more than 18 years.

Page 4, Lines 8-11: This sentence is confusing and misleading. Synchronized wind and gas data is a requirement for the eddy covariance method. It can be achieved by co-locating the gas analyzer and the sonic anemometer, as in the IRGASON instrument. The spatial co-location eliminates any wind dependent time lags between the vertical wind and the sclalar of interest. The need for spectral corrections as proposed by Moore (1986), Horst (1997) and Horst and Lenschow (2009) is also eliminated. The spatial separation between sensors is a tradeoff between the spectral attenuation and the effects of flow distortion errors caused by the ultrasonic transducers, the supporting structure of the anemometer and the gas analyzers. Smaller diameter analyzers with horizontally symmetrical structure, as the EC150 and the IRGASON, are aerodynamic and can be positioned close to the sonic anemometer without causing significant attenuation of vertical wind fluctuations, Fig. 4C Horst et al. (2016).

Page 4, Line 16: Reference for the Hydra-IV, CEH should be provided. I am not aware of any studies reporting flow distortion issues of the Hydra-IV, CEH. If such references exist, they should be provided or the Hydra-IV sensor should be removed from the list.

Page 6, Lines 17-18: Under certain conditions, flux biases could be drastically different from biases in covariances since the density effects (WPL) could strongly modulate the final flux calculations.

Page 7, Lines 27-28: Details about the conditions of the experiment should be provided. Spectra and co-spectra with 50Hz Nyquist frequency should be shown.

Page 10, Lines 7-10: SDM protocol should be mentioned as proven technological solution that guarantees sufficient synchronicity between sensors. There is a conflict between promoting collaboration between manufacturers and protecting technical ideas with patents. The authors should not recommend that the scientific community collaborate with manufacturers of EC equipment unless they are willing to share the ideas that they patented with United States Patent 9,759,703 B2. This patent claims protection of an IEEE adopted standard, Precision Time Protocol, for synchronization between eddy-flux instrumentation.

Page 17, Figure 7: The authors should explain the cluster of points at the high end of the frequencies for the time series with the 180 microseconds STE. It would be more appropriate to include Ogives plots to show if the two signals become out of phase at some frequencies causing negative values for the covariance.

REFERENCES:

Moore, C.J., 1986. Frequency response corrections for eddy correlation systems. Boundary-Layer Meteorology, 37: 17-35

Horst, T. W.: A simple formula for attenuation of eddy fluxes measured with first-order-response scalar sensors, Bound.-Lay. Meteorol., 82, 219–233, 1997.

Horst, T. W. and Lenschow, D. H.: Attenuation of Scalar Fluxes Measured with Spatially-displaced Sensors, Bound.-Lay. Meteorol., 130, 275–300, 2009.

United States Patent 9,759,703 B2. Systems and Methods for Measuring Gas Flux

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