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Atmospheric Measurement Techniques Discussions

Technical Note: Possible errors in flux measurements due to limited digitalization

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Abstract. Recently reported trends of carbon dioxide uptakes pose the question if trends may results of the digitalization of gas analysers and sonic anemometers used in the 1990s. Simulating a 12-bit digitalization and the instrument error reported for the R2 and R3 sonic anemometers elsewhere, the influence of these deficits in comparison to the 16-bit digitalization were quantified. Both issues have an effect only on trace gas fluxes of small magnitude, mainly for the carbon rather than for the water vapour fluxes. The influence on the annual net ecosystem exchange is negligible, because, errors resulting from the gap filling are much larger.

1 Introduction

Nowadays, data sets of FLUXNET sites are available and many papers have been published which analyse and compare these data and link them to ecosystems, phenology, regions, and climate (Baldocchi, 2008; Williams et al., 2012; Keenan et al., 2013; Keenan et al., 2014; Kutsch and Kolari, 2015; Baldocchi et al., 2016; Babel et al., 2017). Besides among the factors with a possible influence on the data is the quantification (digitalization) error (Ifeachor and Jervis, 2002), arising from the use of a limited 12-bit-digitalization of turbulence data about 15–20 years ago (Vickers and Mahrt, 1997). This error could induces trends (Foken, 2017) and has, up to now, not really been investigated. The influence of the digitalization error on flux calculations is the topic of this short note. A effect similar to the effect of the digitalization error could have been caused by the instrument error reported for the formerly used R2 and R3 sonic anemometers before 2003 (Foken et al., 2004, found by Chr. Thomas, University of Bayreuth, 2002). The problem was indicated when applying these sonic anemometers for a relaxed eddy accumulation (REA) system, where the vertical wind velocity near 0.00 m s-1 must be accurately measured. The problem was reported to manufactory (now: Gill Instruments Ltd, Lymington, UK) and the firmware was updated. For this study a data set output with 16-bit-digitalization will be compared to the same data simulating a 12-bit-digitalization.

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2 Material and Methods

2.1 Data sets for the analysis

The data used for this study are from the FLUXNET site (DE-Bay) Waldstein-Weidenbrunnen (50°08'31" N, 11°52'01" E, 775 m a.s.l.), which is located in the Fichtelgebirge Mountains in the northeast of Bavaria (Germany), where Norway spruce (*Picea abies*) forest dominates. Measurements of energy and carbon dioxide fluxes started in 1996 on the top of a 32 m high walk-up scaffold tower. Possibly affected time series are the measurements made with the R2 and R3 sonic anemometer from 1997 to 2006 and the LiCor 6262 gas analyser (LI-COR Inc., Lincoln, NE, USA) from 1997 to 2002. The complete data set was analysed by Babel et al. (2017).

The instrumentation of not only the Waldstein-Weidenbrunnen site, but all FLUXNET sites, has changed dramatically, occurring mainly at the beginning of the 2000s. At this time, the first commercial open-path instruments for carbon dioxide and water vapour concentration measurements became available. Before 2000 only closed-path instruments were used, having only a 12-bit signal digitalization, while later devices had 16-bit or more.

One year of measurements collected during 2012 from the METEK sonic anemometer USA-1 (METEK GmbH Elmshorn, Germany) und the LiCor 7500 gas analyser were used for this study. Turbulent fluxes of carbon dioxide and water vapour were calculated using the internationally-compared software package TK2/TK3 (Mauder et al., 2008; Fratini and Mauder, 2014; Mauder and Foken, 2015). All necessary corrections and quality checks were done in accordance with micrometeorological standards (Foken et al., 2012). Coordinate rotation was carried out using the planar-fit method (Wilczak et al., 2001) for each separate month, based on an analysis by Siebicke et al. (2012). The net ecosystem exchange (NEE) is defined as the sum of the vertical eddy-covariance carbon dioxide flux and the change in storage of the air column below the sensor.

2.2 12-bit-digitalization

The effect of limited amplitude resolution of fluxes of small magnitude was already discussed by Vickers and Mahrt (1997) and is illustrated in a time series of the carbon dioxide concentration in Fig. 1.

The typical characteristics of 12-bit- and 16-bit-digitalization are shown in Table 1. The problem is more significant for carbon dioxide than for water vapour because the carbon dioxide fluctuations are much smaller in relation to measurement range than those of water vapour. Furthermore, under stable stratification the carbon dioxide concentration can be 3- to 4-times higher than the mean concentration and the measurement range must be extended. The output resolution of all sonic anemometers is currently at least 0.01 m s-1 and is not affected by any digitalization error. A quadrant (hole) analysis of all data points (20 Hz sampling rate) for one hour of the vertical wind velocity and the carbon dioxide concentration is shown in Fig. 2. The included density distributions show only small differences between both digitalizations and are not significantly affected by the binned concentration data, which explains the small impact of the digitalization error on the computed flux.

2.3 Instrument error of R2 and R3 sonic anemometer

The R2 and R3 sonic anemometers had, up to 2003, instrument error (Foken et al., 2004) such that the R2 did not output vertical wind velocities of w = –0.01 m s^{-1}, but added these values to the digitalization step 0.00 m s^{-1} (Fig. 3). For R3 there was a similar pattern every 0.07 m s^{-1} for negative w-values and every 0.14 m s^{-1} for positive w-values.

3 Results and discussion

3.1 Effect of 12-bit-digitalization

From a theoretical point of view the digitalization error should only impact small magnitude fluxes, mainly in winter due to small magnitude of perturbations. These fluxes may subsequently impact gap filling for low temperatures and annual budgets. In Fig. 4 only fluxes smaller than |0.003 mmol m^{-2} s^{-1}| are shown. In summer, even for small net fluxes, the amplitude of the fluctuations is high and no effect on the fluxes can be seen. In winter the data are much more scattered and the respiration fluxes may be overestimated by approximately 5 %. Similar effects on cumulative fluxes could also be shown for incorrectly applied correction under these conditions (Oechel et al., 2014).

3.2 Effect of instrumental errors of the sonic anemometers R2 and R3

The original data of the vertical wind velocity were replaced by data simulating the error of the R2 sonic anemometer. The simulated errors hat no significant impact on the results (Fig. 5 left, compare with Fig. 4 right). To isolate the effect of the coordinate rotation from that instrument error on to the fluxes the analysed was repeated with unrotated data in which the digitalization step 0.00 m s-1 bin was empty. As shown in Fig. 5 right, the effect of the sampling error of R2 is negligible, even for low fluxes and vertical wind velocities in the relevant range. Identical results were obtained when simulating the R3 sonic anemometer error (produced before 2003).

3.3 Influence on longer time series

To investigate the influence of digitalization errors on annual sums of the NEE the data of 2012 were analysed and the results are shown in Table 2. The time series was not gap filled, therefore respiration date are partly missing and NEE is larger than usual. Simulating the digitalization error no significant impact on annual carbon budget could be detected, except for reduction of the respiration for fluxes smaller |0.003 mmol m^{-2} s^{-1}| in winter (DJF). The R2-error has no influence on the results.

4 Conclusions

Since long time-series for carbon fluxes bare high relevance for ecosystem behaviour, investigations of older data sets should be undertaken with care due to possible artefacts resulting from changes in instrumentation and data handling. The present study showed that the effect of a limited 12-bit-digitalization of the gas analyser LiCor 6262 and an instrumental error of the sonic anemometers R2 and R3 showed no effect on summer data and for annual budgets. Only selected data of low magnitude fluxes show increased scatter and differences of approximately 5 % due to the digitalization error – mainly in wintertime. The effect of the R2 and R3 instrument error was negligible. Because low fluxes and fluxes in wintertime are often discarded from quality routines and gap filled. Hence, errors resulting from the gap filling (Moffat et al., 2007) are much larger than the errors reported here.

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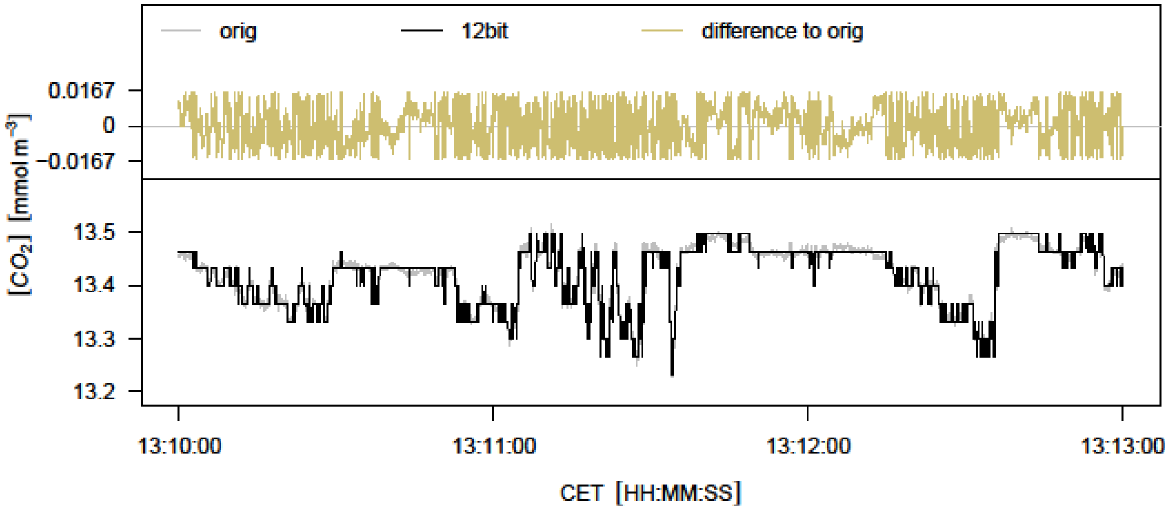

Figure 1: Carbon dioxide concentration on 02 August 2012 measured with LiCor 7500 (orig.) and reduced to 12-bit resolution. In the upper panel the difference between both signals is shown and in the lower panel both signals show the typical ramp structures above the spruce forest.

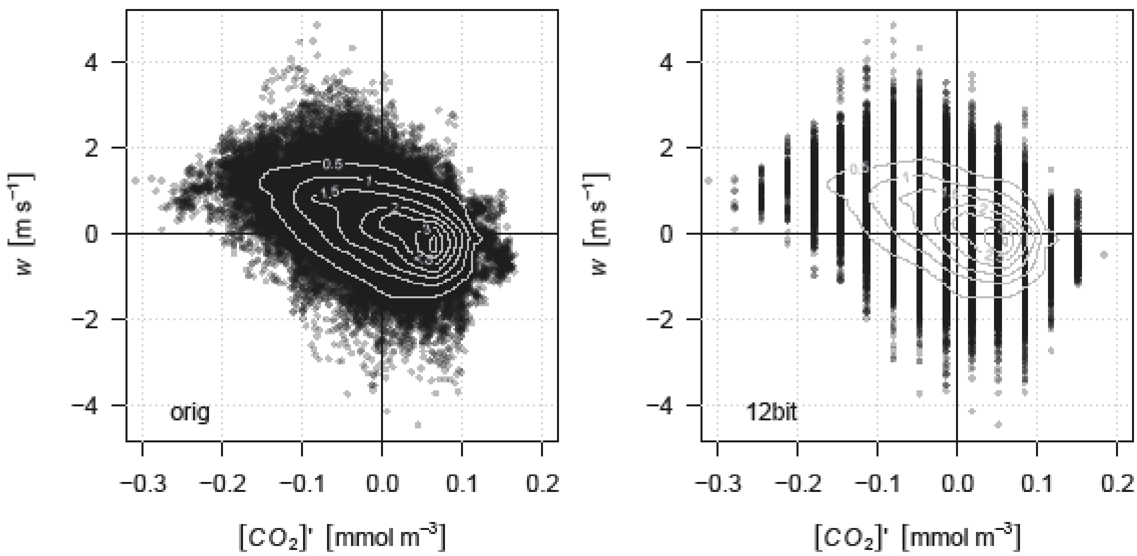

Figure 2: Quadrant (hole) analysis of all data points (20 Hz sampling rate) of the vertical wind velocity and the carbon dioxide concentration for one hour (summer at noon) with 16-bit-digatalization (left) and reduced to 12-bit-digitalization (right). A normalized density distribution in form of isopleths is included in both figures.

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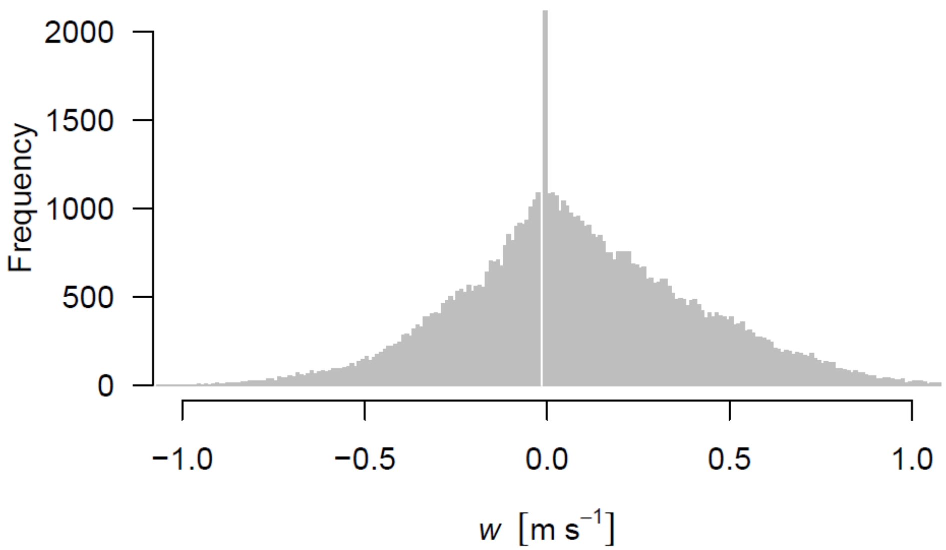

Figure 3: Probability density plot of the vertical wind velocity for one hour (summer at noon) with the manipulated instrumental error of the R2 sonic anemometer.

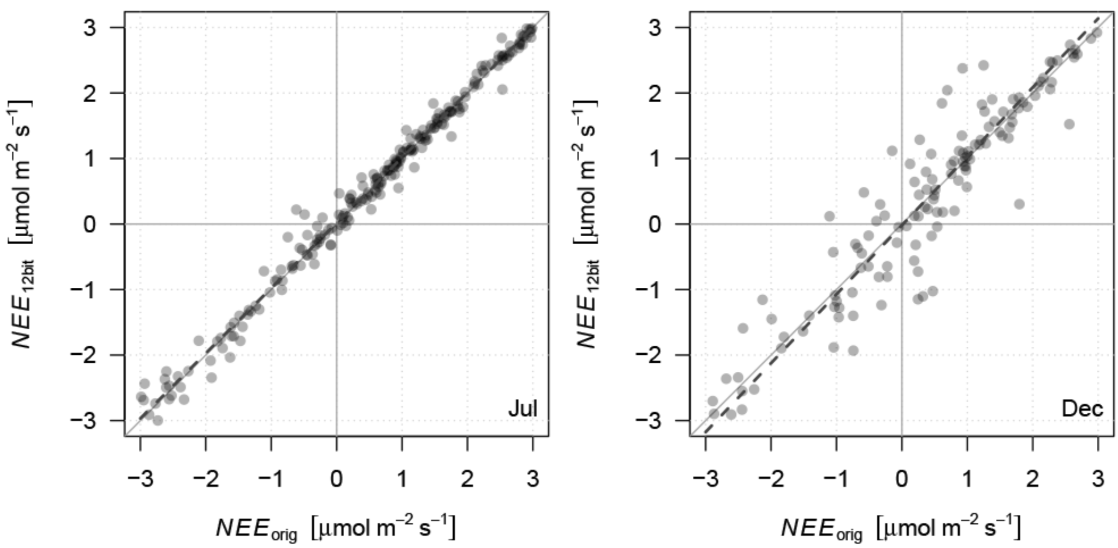

Figure 4: Comparison of the original NEE measurements at Waldstein-Weidenbrunnen site in 2012 (original 16-bit-digitalization) with calculations using data with 12-bit resolution for the gas analyser in summer (July, left, NEE_{12bit} = 0.995 NEE_{org} ± 0.000 mmol m^{-2} s^{-1}, R^2 = 0.99, N = 219) and winter (December, right, NEE_{12bit} = 1.052 NEE_{org} ± 0.000 mmol m^{-2} s^{-1}, R^2 = 0.87, N = 129). Only data smaller than |0.003 mmol m^{-2} s^{-1}| are shown.

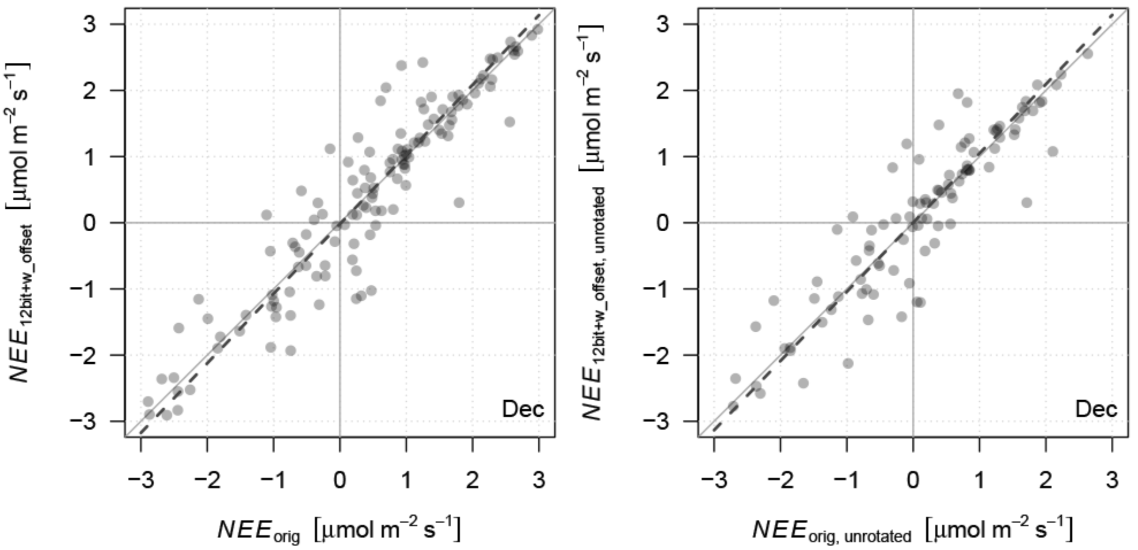

Figure 5: Comparison of the original NEE measurements at Waldstein-Weidenbrunnen site of December 2012 (original 16-bit-digitalization) with synthetic data with 12-bit-digitalization for the gas analyser and the instrument error (*w*-offset) of the sonic anemometer R2. In the left figure the data were rotated (compare with Fig. 4 right, $NEE_{12bit\_w\_offset}$ = 1.052 NEE_{org} ± 0.000 mmol m^{-2} s^{-1}, R^2 = 0.87, N = 129) and in the right figure were not ($NEE_{12bit\_w\_offset\_unrotated}$ = 1.045 $NEE_{org\_unrotated}$ ± 0.000 mmol m^{-2} s^{-1}, R^2 = 0.83, N = 97). Only data smaller than |0.003 mmol m^{-2} s^{-1}| are shown.

Table 1: Characteristic resolutions for water vapour and carbon dioxide concentrations with 12-bit- and 16-bit-digitalization, italic data were used for simulation

	12-bit-digitalization	16-bit-digitalization
Sampling points within the measurement range	2^{12} = 4,096	2^{16} = 65,536
Measurement range for water vapour	0 – 75 ppth or about 0 – 3250 mmol m^{-3}	
Measurement range for carbon dioxide	0 –3,000 ppm or about 0 – 130 mmol m^{-3}	
Digitalization step for water vapour	0.018 ppth or *0.8 mmol m^{-3}*	0.0011 ppth or 0.05 mmol m^{-3}
Digitalization step for carbon dioxide	0.73 ppm or *0.033 mmol m^{-3}*	0.046 ppm or 0.002 mmol m^{-3}

Table 2: Annual sum of NEE with 12-bit- and 16-bit-digitalization and with and without R2 instrumental error (the data were not gap filled, therefore the sum is larger than usual, relevant differences italic)

Data selection	12-bit- digitalization	16-bit-digitalization	Number of (30 minute) data points
All data, without R2 error	-799.73 g C m^{-2}	- 798.27 g C m^{-2}	8419 of 17520
All data, with R2 error	-799.71 g C m^{-2}		
Only data < |0.003 mmol m^{-2} s^{-1}|, without R2 error	33.663 g C m^{-2}	33.145 g C m^{-2}	2678 of 17520
Only data < |0.003 mmol m^{-2} s^{-1}|, with R2 error	33.660 g C m^{-2}		
Only data < |0.003 mmol m^{-2} s^{-1}|, without R2 error (only winter, DJF)	*1.328 g C m^{-2}*	*1.150 g C m^{-2}*	284 of 4320
Only data < |0.003 mmol m^{-2} s^{-1}|, with R2 error (only winter, DJF)	1.328 g C m^{-2}		