**Atmospheric
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Discussions**

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## *Interactive comment on* "A compact and stable eddy covariance set-up for methane measurements using off-axis integrated cavity output spectroscopy" *by* D. M. D. Hendriks et al.

**D. M. D. Hendriks et al.**

Dear referee,

We would like to thank you a lot for reviewing our paper A compact and stable eddy covariance set-up for methane measurements using off-axis integrated cavity output spectroscopy. All comments have been read carefully and when necessary we adjusted text and figures according to your comments. Below, you will find all our responses to your remarks. First, our responses considering contents, analyses, tables and figures are discussed. Second, our replies to the merely textual comments are listed. We think that the manuscript has improved a lot from all the adjustments.

Best regards,

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On behalf of all authors, Dimmie Hendriks

General comment The manuscript could be shortened by careful editing of text and figures. - By processing the more specific comments of the referees, the applied changes contributed to shorten the manuscript.

Specific comments Abstract: Line 15-18: where were $CH_4$ emissions measured? - The sentence is extended to: &#8230;.. in a closed path eddy covariance field set-up in a peat meadow.

Page 11591 Line 7-11: is the ICOS technique linear? - Yes, the measured fractional absorption of light at the methane resonant wavelength is an absolute measurement of the methane in the cell. This is added to the text. Does it really operate autonomous in the field? - Yes, text is clarified by removing claimed.

Page 11592 Line 2-8: Is the power required for the scroll pump included in the 180 W? - No, pump is not included in this. Power required for the external pomp is 600 W other power specifications are similar to those of the FMA. This is added to the text at page 11592, line 9. Line 23: It&#8217;s not clear to me why the volume of air in the cell adjusted for the ratio of pressures is important. - We have made this too complicated. The actual pumping speed of the scroll pump is app. $5.50Œ10-3$ m3 s-1 for a pressure in the measurement cell of 190 to 210 hPa, which explains all. Lines 19-25 The high flow ....... the measurement cell. is removed and the sentence However, at the required pressure of 190 to 210 hPa the actual pumping speed is approximately 5.50 m3 s-1 is added at line 8 of the same page.

Page 11594 Line 3: subscript for $x[(s+1)k+l]$ is not easy to understand. Same for the explanation of l. - This subscript aims to find the correct sample of a subgroup l = 1 to l = k. The sentence is changed slightly to provide more clarity: In this equation A is an average of the $CH_4$ concentration, k is the number of elements in subgroup x, l is the sample-number in the subgroup, s is the subgroup number and m&#8217; the number of independent measurements.

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Line 19-23: Just using Equation 4, the answer I get is higher than 0.00781 and also question about difference in units on both sides of Eq. 4. What happens to the root of Hz? We recalculated the equation, but came to the same result: $=(6.1 \times 10^{-4})^{1/2} \times 10^{-1/2} = (2.47 \times 10^{-2}) \times (3.16 \times 10^{-1}) = 7.81 \times 10^{-3}$ pbb Hz$^{-1/2}$

However, the Hz$^{-1/2}$ was missing from the unit ppb Hz$^{-1/2}$, this is added in the text.

Page 11596 Line 15: Why is &#964; the volume of outside air in the cell divided by pumping speed? The next sentence The &#964; includes an underestimation of 37% (1/e) of the signal, which was corrected for during the data processing. is confusing - We agree with the referee and will change the paragraph about the response time to give more clarity on the subject:

In general a sampling rate of 10Hz, with a Nyquist frequency of 5Hz, is used for eddy covariance techniques (Aubinet et al, 2000; Kroon et al. 2007). Therefore an instrumental time response of 10Hz or greater is required in order to correlate with the wind measurements made with the 3-axis ultrasonic anemometer. The measurement rate of an instrument is determined by both electronic signal processing and by the signal response time of the measurement cell (&#964;) (Nelson et al., 2004). Electronic signal processing is dependent on the spectral complexity of the measurement technique as well as the technical design of the ICOS technique. In the case of the FMA, this was defined by the designers (LGR Ltd.) as 20Hz. The limiting factor of the maximum sampling rate is often &#964;, which could be determined by the volume of the measurement cell ($0.55 \times 10^{-3}$ m3) divided by the actual pumping speed (app. $5.50 \times 10^{-3}$ m3 s-1) giving a flow response of 0.10 s. Additionally, instrument response time was determined by applying a step change in concentrations at 20Hz sampling rate (Fig. 5) (Moore, 1986; Zahniser et al., 1995; Nelson et al., 2004). Each data point is the average mixing ratio of multiple step change events at a certain t (time elapsed since step change in concentration). The flow response time is defined by the exponential fit to the decay of the CH4 mixing ratio and was calculated &#964; = 0.11 s by Eq. 4.

[CH4]t = [CH4]t=0 e (-t/ τ;) (6)

In this, sensitivity to tube length could be observed (Fig. 5). Since the effect of tube damping is corrected separately, and τ only refers to the response of the instrument itself, the actual τ is determined as 0.10 s. The value of τ was used to correct for the dampening of the signal in the instrument (Moore et al., 1986).

Page 11597 Line 13: Not clear what angle of attack dependent correction is. - The angle of attack dependent correction involves the correction for the potential for sonic anemometer (co)sine errors to affect eddy flux measurements. In the paper by Gash and Dolman (2003) similarity theory showed that the standard deviation of the instantaneous angle between the wind vector and the horizontal (the angle of attack), depends on surface roughness, measurement height and atmospheric stability. The normalised flux-angle distributions showed that the sonic anemometer operated outside its manufacturer's specified angle-acceptance envelope for 20% of the daytime fluxes in an open environment and 50% of the daytime fluxes in a forest. In the paper the implications for the design of eddy flux measuring systems are discussed. - We think that readers are referred to the most important papers about this subject in the current text.

Page 11598 Line 15-16: How can the data from the previous day be used to fill in the missing values? If the gap is fairly short (˜1minte or less). I would think this would just cause errors. If it is for an entire ½ hour period that might be OK. But why not just leave the data point out, if in fact no/not enough valid data were available. - We agree with the referee that for this paper, filling gaps in the data is not required and might introduce a non-relevant discussion into the paper. Instead, we will focus on the nature of the gaps. The first paragraph of this section is changed to:

From the eddy covariance data series 11% consisted of gaps due to failure of the eddy covariance set-up caused by rain events and instrumental errors. Additionally, 3% of the data series consisted of spikes (CH4 flux > 100.0 nmol m-2 s-1 and CH4 flux < -10.0 nmol m-2 s-1) and were removed from the data set. …… CH4 flux

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data measured during periods with u* < 0.09 m s-1 occurred at 12% of the data series and where removed too. The total amount of data gaps accounted for 26% of the whole data series. CH4 fluxes ánd CO2 fluxes (net ecosystem exchange (NEE)) were plotted for a two week period in June 2006 at the Horstermeer site (Fig. 8). Although the CH4 fluxes are rather variable over time, a diurnal cycle can be observed with low emission during the night and high emission during the day. CO2 fluxes have a similar, but opposite, diurnal cycle. The observed CH4 fluxes consisted mainly of emission and had an average of 29.7 nmol m-2 s-1, while the typical maximum CH4 emission was approximately 80.0 nmol m-2 s-1. The typical minimum flux was approximately 0.0 nmol m-2 s-1 and at three occasions a small uptake was observed.

The decision not to fill the gaps also has an influence on the results of the simulated methods with lower sampling rates. Table 2 as well as the text in the results and conclusions section have therefore changed.

Page 11599-11601 At the end of the first paragraph of the section about alternative measurement techniques the following sentence is added: Here, the raw (10Hz) data were manipulated to simulate disjunct eddy covariance, 1Hz eddy covariance and REA. - The b-value for the momentum of CO2 and water vapour fluxes (both measured by the open path Licor) was similar to that for the CH4 fluxes measured with the FMA. Since these variables are often measured at eddy covariance sites even where an external power source is not available, the b-value found with manipulation of those data will give a good indication of the b-value needed for the REA system. This is added to the text partly in the &#8216;Results&#8217; section and partly in the &#8216;Conclusions and Discussion&#8217; section.

Figure 2: We do think this figures is informative, giving an overview of the set-up with all its&#8217; instruments and parts. Figure 5: We do think this figures is informative, visualising the explanation of the response time. The formula however, is shifted to the text (see above). Figure 6: This figure is adjusted after additional analyses and will show graphs with power and co-spectra for w and CH4 of observations averaged

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over 6 half hour periods as well as theoretical power and co-spectra. Figure 8: After removing the gap filled data periods, the figure has changed slightly. Additionally, for more clarity, the graph for CO2 is separated from the CH4 graph. Figure 9: We do think this figures is informative, visualising the explanation of the comparison with flux chamber measurements. Figure 10: is removed from the paper.

Text editing Abstract Company names are removed from the abstract. Line 6: 20Œ103 to 20 0Œ103 m is changed to 2-20Œ103 m. Line 8: tested to be 0.10 s is changed to determined to be 0.10 s. Line 10: 3 axis is changed to 3-axis. Line 13: parentheses on eddy covariance are removed. Line17-18: minus sine will be forced to stick with the 20.

Page 11589 Line 8: is 1 (by definition IPCC, 2007) is changed to is by definition 1 (IPCC, 2007) Line 11: is therefore only sparsely applied is changed to has therefore only been sparsely applied. Line 13: advantages of the eddy covariance technique for measuring is changed to advantages of the eddy covariance technique compared to other techniques for measuring. Line 14: none-the-less is changed to nonetheless. Line 16: eighties is changed to 1980s. Line 22: a comma is added after module. Line 23: Quantum cascade laser is changed to Quantum Cascade Laser. Line 25: the is removed from the TDL spectrometry. Line 26: a comma is added after module. Line 28: thus imply is changed to have thus implied.

Page 11590 Line 6: tested on precision is changed to tested for precision. Line 6: data processing is assessed is changed to data processing capabilities are assessed Line 8: existing techniques is changed to existing measurement techniques. Line 10: are performed is changed to were performed. Line 15: In 1998 a measurement cell with highly reflective mirrors was combined with a highly specific narrowband laser system (O&#8217;Keefe et al., 1998) is changed to A measurement cell with highly reflective mirrors was combined with a highly specific narrowband laser system by O&#8217;Keefe et al. (1998). Line 25: he laser beam is corrected to the laser beam. Line 26: under a slight angle after which the laser beam is reflected is changed to at a

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slight angle, after which it is reflected.

Page 11591 Line 2: 2Œ103 to 200Œ103 m is changed to 2-200Œ103 m. Line 4-5: in the measurement cell per measurement, might change as a result of changes in reflectivity of the mirrors in the measurement cell is changed to in the cell for each measurement, might change as a result of changes in reflectivity of the mirrors in the cell. Line 14-16: an external pump is needed to maintain the required response time. Internal voltage of the FMA should be maintained at 5.20 to 5.25V and the pressure in the measurement cell should be between 190 and 210 hPa is changed to an external pump is needed to maintain the required response time, and the pressure in the measurement cell should be between 190 and 210 hPa. Line 17: The MRT may not drop below 3 to 3.5 &#956;s is changed to The MRT cannot be allowed to drop below 3.5 &#956;s. Line 21: can be done by the user himself in a dust-free environment is changed to can be done in a dust-free environment.

Page 11592 Line 3: Design of closed path is changed to Design of the closed-path. Line 5: with a scroll pump that creates the under pressure in the measurement cell which is required for the 10 Hz sampling rate. is changed to with a scroll pump that maintains the correct pressure in the measurement cell required for sampling at 10Hz. Line 16 and 18: towards is changed to toward. Line 18: free steel is changed to stainless steel. Line 26-27: trough is changed to through three times. Line 27: Licor 7500 is changed to LI-7500.

Page 11593 Line 2-3: directed to the main wind direction is changed to directed into the prevailing wind. Line 7-8: determined by determining the covariance of that atmospheric property is changed to determined by the covariance of that property and the vertical velocity, as shown in Eq. 2.. Line 12: pur pose is changed to purpose.

Page 11594 Line 5: a space is inserted after subgroup,. Line 19: the y-axis interception point at the minimum is changed to the y-intercept at the minimum. Line 24-25: the temperature (Tcell) is changed to the cell temperature (Tcell).

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Page 11595 Line 1 to 7 are changed to: The influence of changing temperature and pressure conditions in the measurement cell (Tcell and Pcell) on CH4 concentration measurements was assessed in the laboratory. During a time series of continuous measurements, a step change in Pcell was induced, while Tcell increased steadily. An effect of the increase of Tcell on CH4 concentration was observed neither from the time series, nor from the correlation plots (Fig. 3). A rapid decrease in the CH4 concentration data was observed 990 sec after the sharp decrease in Pcell. However, this feature did not result in a clear correlation between CH4 concentration and Pcell. Also, this type of Pcell changes did not occur under normal circumstances when Pcell had a stable value near 210 hPa. Line 9: respectively is removed. Line 11: turned of is changed to turned off. Line 20: gas Chromatograph is changed to gas chromatograph. Line 23: None the less is changed to Nonetheless.

Page 11596 Line 1: winds from eastern, continental, direction prevailed, which accounted&#8230; is changed to prevailing winds were from the east (continental). This accounted&#8230;. Line 10: the 63% (1 - 1/e) is changed to the 63% point (1-1/e).

Page 11597 Line 5: 1000 times the length of the diameter is changed to 1000 times the inner diameter. Line 10: Licor 7500 is changed to LI-7500. Line 19: spectra of the w, T and is changed to spectra of w, T, and Line 27: well established is changed to well-established.

Page 11598 Line 8: CO2 of night time periods is changed to CO2 from night time periods. Line 10: CH4 eddy covariance data-series and comparison with flux chamber measurements and high tower data is changed to Intercomparison of eddy covariance and flux chamber measurements. Line 21: Uncertainties of the CH4 emissions is changed to Uncertainties in the CH4 emissions and night time is changed to night time. Line 27: Photo Acoustic is changed to Photoacoustic.

Page 11599 Line 6 and 9: the 10th of June and the 3rd of October are changed to On June 10 and On October 3. Line 10: while that of the eddy covariance was is

changed to while that from eddy covariance was. Line 17-18: generate results of certain reliability too is changed to can generate reliable results too. Line 22: inevitable to operate the set-up it is changed to necessary for operation.

Page 11600 Line 15: all variables of is deleted. Line 17: drawn to is changed to drawn into. Line 18: switching was is changed to switching is. Line 22: samples were taken is changed to samples are taken.

Page 11601 Line 9-10: &#8230; at a half hourly basis. On daily basis &#8230; is changed to &#8230; on a half hourly basis. On a daily basis &#8230; Line 14-15: of averaging turbulent perturbations, enabling the set-up to measure CH4 molecules transported by high frequent atmospheric turbulence (>1Hz). is changed to of averaging turbulent perturbations, in which CH4 is transported by high frequency atmospheric turbulence (>1Hz). Line 16: in the Horstermeer polder is changed to at the Horstermeer measurement site. Line 27: well suitable is changed to suitable.

Page 11602 Line 2: second new in sentence is deleted. Line 3: satisfactory is changed to satisfactorily. Line 4: techniques the absence is changed to techniques, the absence. Line 5-6: the relatively user friendliness is changed to the relative user friendliness. Line 12-13: Cleaning of the mirrors, however, is a relatively simple procedure that can be done by the user himself in a dust-free environment. is removed. Line 16-17: high and indeed are deleted. Line 18: tested to be 0.10 s is changed to determined to be 0.10 s and second part of sentence is deleted. Line 18-19: with a 37% underestimation of the measured signal, which was corrected for during the data processing. is changed to implying a maximum sampling rate of 10Hz. Line 22: very well suitable&#8217; is changed to suitable. Line 26: similar is changed to similarly. Line 27: CH4 emissions are rather variable over time and show a diurnal pattern. is changed to CH4 emissions at the Horstermeer site were rather variable over time and showed a diurnal pattern. Line 28-29: verbs are changed to past tense.

Page 11603 Line 3: with the QCL is changed to with QCL. Line 7: measurements

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was is changed to measurements, it was. Line 12: the set-up was tested for three measurement techniques is changed to the data were used to test three measurement techniques. Line 19: reasons; is changed to reasons,.

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