bg-2018-435

Author response to comments of referee #2

We'd like to thank reviewer #2 for his careful review and appreciate his valuable comments, which significantly improved the manuscript.

In the following list, the referee comments are printed in *italic* and author responses are printed in blue. For the majority of the minor (language related) comments we fully adopt the referee suggestions. Below only the comments are listed that required a specific response.

General comments

The authors used gap filling approaches to fill gaps in their eddy covariance N2O flux dataset but here was not much discussion about the gap filling results. My suggestion is that this discussion should be expanded.

We used only one approach (LUT) for the gap filling of our EC fluxes, as mentioned in Section 2.5.3. This approach was chosen based on the cited evaluation by Mishurov and Kiely (2011) who discussed different gap filling approaches is more detail. It was not the objective of this study to assess the performance of gap filling approaches. However, we used the variability between LUT and three other approaches for estimating the uncertainty of the gap filling procedure.

In addition, it would be important to include more details in the methodology on the EC and chamber measurements and scaling approaches (see specific comments). Some sentences in the text are difficult to understand, so the writing requires further work. I also noticed some grammar mistakes in the text. I recommend the authors to perform a thorough review of the manuscript to correct these mistakes before resubmitting the manuscript.

We think, the methodology on the EC and chamber measurements (including scaling approaches) is already described very extensively with about 6.5 pages (excluding figures). Nevertheless, we intend to include most of the specific comments on methodology issues (see answers to specific comments below).

Regarding the language related issues, we agree with the reviewer and will perform a thorough review to correct these mistakes.

Specific comments

Page 1

L12 – replacing "season 2016" by "season of 2016". In addition, I suggest including the number of dairy cows for each herd.

Will be changed accordingly. We will include the number of dairy cows (12 for each herd).

L15 – "Excreta patches and background surfaces on the pasture were identified manually". I suggest to be more specific here by saying that urine patches were identified based on the soil electric conductivity.

We will rephrase the sentence to "After different grazing rotations, background and urine patches were identified based on soil electric conductivity measurements while fresh dung patches were identified visually. The magnitude and temporal pattern of these single emission sources were measured with a Fast-box (FB) chamber".

L20 – "(960 ± 219 g N2O-N, or 25 %)" This number is a little confusing. What does the 25% represent and shouldn't the emission units be expressed in per area?
We agree with the reviewer that the number is a bit confusing. The value/units represent integral emissions for the entire pasture area and the investigated grazing period. In order to prevent confusion and misunderstandings, we will change the units of this type of results (in the abstract and in the main text) and express them in units of N_2O -N cow^{-1} h^{-1}, which has an equivalent meaning. The "25%" represent the relative change of emissions between the two grazing systems. This will be clarified by including the emission values of the two systems and rephrasing in the following way: "Neglecting emission periods influenced by fertilizer applications resulted in significantly higher grazing related emissions per cow and grazing hour in system G (0.270 g N_2O-N cow^{-1} h^{-1}) compared to system M (0.201 gN_2O-N cow^{-1} h^{-1})."

L29 – replace "In the atmosphere, nitrous oxide" by "Nitrous oxide". In addition, include the appropriate citation for this sentence.
Will be changed accordingly and we will add a reference to the IPCC (2014).

L30 – replace "it has a strong potential" by "N2O has a strong potential". I noticed that the replacement of nous by pronouns in some sentences throughout the text can compromise the clarity of those sentences. I suggest the authors to be as direct as they can in their sentences for the sake of clarity.
Will be changed accordingly. Furthermore, we will try to locate those replacements and use the proper nouns.

Page 2
L1 – "especially by cows". Are you referring specifically here to dairy cows? If so, please specify.
No, we refer to cows in general.

L3 to L5 – "Directly applied on a pasture soil. . ." this sentence is awkward and needs to be reworded.
We will reword the sentence to:
Once applied to the pasture soil, the reactive nitrogen of excreta is transformed by microbial nitrification and denitrification processes and significant amounts of N_2O can be produced as a by-product."

L17 – replace "(e.g. EF of 0-14% of applied urine N, n=40; Selbie et al., 2015) and many of those studies measured the" by "(e.g. EF of 0-14% of applied urine N, n=40; Selbie et al., 2015). Many of those studies measured the". In addition, give some examples of the "many of those studies".
Will be changed accordingly and we will give some examples of those studies (Bell et al., 2015; Chadwick et al., 2018).

L20 – "these emissions" which emissions?
We will rephrase the sentence to make it clear that we mean the emissions associated to animal excreta. "The more efficient use of fed N is essential to reduce the emissions associated to animal excreta. "

L20 - "(e.g. Arriaga et al., 2010)" provide more examples of studies and more the citation to the end of the sentence.
We will provide more examples and put the citations at the end of the sentence.
"…N excreted by the animals (e.g. Arriaga et al., 2010; Dijkstra et al., 2013; Yan et al., 2006)."

L24 – "real practice conditions". Do you mean real management conditions?
We will rephrase the sentence as follows: "…but corresponding emission experiments under real grazing conditions for a full season, to our knowledge, have not been reported hitherto."

L23-24 – "experiments. . . are very rare". Cite some of the existing ones.
Actually, to our knowledge, no comparable experiment exists. We will rephrase the sentence. See also previous comment.

L26 –"and to attribute them to certain emission drivers" this statement needs to be reworded for clarity.
We will rephrase to "…to attribute the measured fluxes to potential emission drivers…".

L30 – "by integration over a larger domain". Integration of what? Do you mean fluxes? Larger domain than chambers?
We will rephrase to "…by integrating fluxes over a larger spatial domain."

Page 3
L8 to 9 – "We aimed at a better understanding of the quantity of the overall pasture emissions, the different emission sources and the reduction of corresponding uncertainties". This sentence is awkward and needs to be reworded.
We will omit this sentence, as it is redundant.

L12 to 13 – provide the experimental period.
We will provide this information (grazing period 2016).

L14 – "annual average rain amount". Is snow also included in the total amount? If so, replace the word "rain" by "precipitation".
Snow is also included, thus we will change "rain amount" to "precipitation.

L15 to 16 – "(about 20 % clay, 35 % silt and 45 % sand" there is no need to show this since this soil texture data are shown in Table 1.
Will be changed accordingly.

L16 – "Soil measurements were performed. . .". Can you be more specific?
This sentence is referring to the preceding sentence (with reference to Table 1). We will rephrase the sentence to: "The sampling for analysis of soil texture and other soil characteristics of different layers were performed at four locations on the pasture in 2013 and 2016."

L19 to 20 – "the fertilization rate was in the order of 120 kg N ha-1 per year between 2007 and 2015". Can you please specify the fertilization timing?
We think, listing the timings of all previous fertilization events since 2007 is unnecessary in the context of the goal of the manuscript (grazing related N_2O emissions). The timing of the fertilisation events of the study year is included in Fig. 2d and will also be added to Fig. 6 in the revised version.

L23 – "12 cows per system.". Please reference figure 1.
We will include a reference to Fig. 1a.

L24 – "with additional maize silage". Was this silage offered to the cows in a different area? Did the silage supplementation influenced the time in which the cows spend in the grazing system?
The silage was fed in the barn when the cows had to go there for milking twice a day. In order to avoid an influence of the supplement feeding on the grazing time, the barn and grazing times were always fully synchronous for both herds/systems.

L30 – "X indicating both systems". I suggest using M or G instead of X to avoid confusion.
We would like to keep the X because it simplifies the text considerably when referring to both systems equally.

Page 4

L15 – "For the comparison with the field-scale EC". Which comparison? Be more specific.

We agree with the reviewer that the sentence is not specific enough. We will rephrase the sentence to "Moreover, the comparison between the field-scale EC method and the small scale chamber measurements required an estimate of the number of dung and urine patches on the pasture."

Page 5

L1 to 2– "Conductivity values exceeding a threshold of 0.15 mS cm-1 were marked as possible urine patches for further chamber measurements." It is important to explain how this electric conductivity threshold was established.

We will add some more information in the text. The threshold of 0.15 mS cm^{-1} was chosen based on pre-experimental tests with artificially applied urine patches on the pasture and areas not affected by grazing for a few month (background). The value of 0.15 mS cm^{-1} was determined as the maximum of the observed background conductivity, but was still far below the observed conductivity of fresh urine patches (see also Fig. 3).

L10 – "taken mainly during dry soil conditions" Can you provide the soil water content associated with "dry soil conditions"?

There is no fixed water content threshold for dry soil condition. Nevertheless, as can be seen in Fig. 2 and Fig. 9, we refer to volumetric soil moisture contents below roughly 0.4, thus clearly lower compared to the ones before July. We will add this information in the revised manuscript.

L18 – "a 40 m 1/4" PA tube allowing". Use metric units do express the dimensions of the tubing. Does 1/4" refer to the internal diameter of the tube? Please specify. What does "PA" stand for?

We will add information as follows: "The sample air was drawn continuously from the FB headspace through a 40 m long polyamide tube (perfluoroalcoxy, O.D. 1/4") to the analyser …"

We would like to keep the tube diameter in inches, as this is the official commercial labelling of this product.

L19 – "The sample flow rate Q was typically around 8 l min-1". Did you use a mass flow controller to keep the flow rate constant?

No, we did not use a flow controller. The flow rate was controlled by the controlled pressure (30 Torr) in the QCL analyser cell and a flow restrictor needle valve at the QCL inlet. The inlet tube represented an additional flow resistance. Since the effect of the valve and the tube were constant over time, the flow also remained quite stable.

L21 – "foam material to avoid uncontrolled air exchange". Was the chamber covered with some insulating material? What was the typical temperature differences within and outside the chamber during these measurements?

No, the chamber was not covered with some insulating material. Nevertheless, as the measurements with a fast-box are very quick (typically within 1-2 minutes), the temperature differences between within and outside the chamber stayed typically below 0.5 °C. Starting a new measurement, the chamber volume was always flushed (by tilting the box by 90 °) until the chamber volume was completely mixed with the air outside the box.

L21 to 22 – "The chamber was also equipped with a GMP343 (Vaisala, FL) CO2 probe to measure the soil respiration." Do you show this CO2 data? If not, I suggest excluding this sentence.

We would like to keep this information, as the CO_2 soil respiration (from the CO2 concentration increase) was used as a proxy to check if the chamber was properly sealed (as discussed in Sect. 2.4.3).

L22 to 23 – "The increase in concentration after placing the chamber on the soil was recorded every three seconds for a time period of about 90 seconds." For your chamber flux calculations, did you take into account the time necessary to purge this long tube right after the sampling line was connected to the analyzer?
Yes, this time was taken into account. In addition we discarded the first and the last 5 seconds of the closure period in the time series from the regression analysis.

Page 6
L2 – "(slow chamber volume exchange and short measurement time)". Can you provide an average value for the chamber volume exchange?
The average volume exchange time is about 40 min. We will add this information.

L13 to 14 – "a thermocouple for air temperature measurement within the chamber, a GS3 probe (see Sect. 2.4.1) and a ML3 Thetaprobe (Delta-T Devices Ltd, UK) for soil moisture and temperature observations (c. 0-5 cm and 0-10cm depth, respectively)." This sentence is a little confusing and needs to be reworded.
We will reword the sentence.

Page 7
L4 – "were fenced to avoid unwanted animal contact". Can you provide the area of the fenced area around the tower?
The fence was in a distance of about 2m around the tower in the main wind direction sectors. In the direction where the QCLs were stationed (trailer at system M, shelter at system G), a larger area was fenced (see white area around EC tower positions in Fig. 1a).

L9 – Does this sonic anemometer infers the air temperature based on the sonic temperature or it has its own temperature sensor?
It infers the air temperature based on the sonic temperature.

L11 – Please provide the pore size of the filters
The Midisart 2000 has a filter pore size of 0.2 µm and the AcroPak has a filter pore size of 0.2 µm. We will include this information in the text.

L16- "The sample frequency of the EC system was generally 10 Hz". Does this mean that there was variation in the sample frequency? Why is that?
We agree with the reviewer about the confusing sentence. The EC system was always operated at 10 Hz.

L18-19 – This sentence is awkward and needs to be reworded.
We will reword the sentence to "Additionally the program visualized the measurements of the N_2O concentrations and fluxes, calculated with an preliminary online flux calculation. The program also allowed to check the EC system by remote access.".

L22 – "The approach is based on. . ." What approach are you referring to?
We refer to the customized program mentioned in the previous sentence. We will rephrase the sentence.

L24 – 500 data points?
Yes, we meant 500 data points.

L28 – "several seconds". Provide the typical time lag value and its standard deviation.
The typical time lag was about 6 seconds for system M and about 7 seconds for system G. We will add this information in the manuscript. But it is not possible to give a meaningful standard deviation

of the 'dynamic' lags determined by the peak position in the cross-covariance function. In many cases, the signal-to-noise ratio of the fluxes were small due to low emissions or non-stationarity. In this cases the 'dynamic' lags were often not meaningful and very large. Due to this reason we applied a lag window filter (see Page 7, line 31) and used an average default lag otherwise. Thus the selected good quality lags were by definition within a window of ±0.61 s).

L31 – "a time window of 0.61 seconds". How was the number determined
The number was determined based on the variability of the determined dynamic lag times. We will include a description how the number was determined in the revised version of the manuscript.

Page 8
L1 – "In order to minimize the effect of non-stationarities in the time series, the 30 min flux was finally calculated as average over six 5 min subinterval flux values.". I wonder what would be the effect of this averaging approach on the low frequency spectral losses of their EC system. Furthermore, if you are already screening the data for non-stationarity (page 8 L24) why to estimate fluxes for these short time intervals?
The low frequency losses were in the range of 1-5 %, based on theoretical calculations (Kaimal cospectra and transfer function for block averaging) and on the comparison of 30 min and 5 min subinterval fluxes. The theoretical approach was used to correct the fluxes for this low-frequency damping effect.
Since a large part of the 30 min N_2O fluxes was more or less affected by non-stationarity effects, the use of the 5 min sub-interval fluxes (to obtain 30 min average fluxes) generally lowered the non-stationarity effects leading to a higher quality of the fluxes (see page 8, line 1-2).

L7 – "half-hourly damping factors". Do you mean dampening factor?
L9 – "damping factors" see comment above
L10 – "damping effect" see previous comment
We think, both terms can be used, but the term "damping" is more commonly used in the EC literature. Therefore we want to keep it here.

L19 – replace "which often result" by ", which often resulted"
We would prefer to use "which often result" to indicate, that this not only happened in the past but is an ongoing issue with EC measurements.

L28 – "It was driven". What is "it" referring to?
The sentence will be rephrased to "The occurrence of data gaps showed a diurnal pattern with stronger data loss during the night, which was driven by the wind pattern with typically stronger wind speeds during daytime and calm nights." in the revised manuscript.

Page 9
L15 – "and it has to be checked". What is "it" referring to?
We are referring to the spatial dimension of the footprint. This will be changed in the revised version.

L22 – "80' 000 trajectories were released backwards in time" replaced by "80,000 fluid particles were released backwards in time". Also, what is the time scale of this simulations? 30-min periods?
Yes, the footprint simulation time scale was 30 min. We will add this information in the text and replace trajectories by fluid particles.

L24 – "systematic uncertainty". Do you mean "accuracy"?
No, we mean the "systematic uncertainty", as described in the referenced articles at the end of the sentence.

Page 10

L1 – I think section 2.6 is out of place. It should come after section 2.7.

We think, it is actually not out of place as Sect. 2.7 builds on data retrieved from Sect. 2.6 (soil moisture / soil temperature measurements). Thus, we would like to keep the structure of the sections.

L2 – what is the datalogger model used in this study?

At system M (north), a Campbell Scientific CR10X data logger was used. At the system G (south), we used the Campbell Scientific CR1000.

L6 – In this section, it would be important to provide the spatial resolution of the grid used for upscaling the chamber fluxes. More details are also necessary on how the authors went from the output of Eq. 2 to the scaled fluxes. Did you generate digital maps of source emissions and then overlapped these maps with a footprint map? What was the software used to do these calculations?

We are not completely sure, whether we understand the question. We did not use a grid to upscale the chamber fluxes to the EC system. Equation 2 was evaluated for each paddock (integrating the particle touchdowns within the respective paddock area) for each 30 min interval. This resulted in a footprint contribution for each paddock which was multiplied by the paddock scale emissions for urine dung and background as described in Fig. 5 and Section 2.7.

We will accordingly improve the description of the upscaling procedure in Sections 2.5.4 and 2.7.

Page 11

L10 – "Occasional negative individual flux values". What is the detection limit of this EC system? I think this would be an important variable to know to interpret these fluxes.

The negative fluxes exclusively resulted in cases, when no peak in the cross-covariance function could be identified (and thus the value at the default lag was used). Thus is can be concluded that the negative fluxes were generally below the detection limit (which was time dependent e.g. due to the varying influence of non-stationarity effects). We will add this information in the text.

Page 12

L3 - "Fluxes of background and dung patches were significantly smaller". Did you perform a statistical test to support this statement?

Yes, we performed the Student's t-test which resulted in p values < 1e-12. But we also think that the results plotted in Fig. 7 are clear in this respect.

Page 14

L25 – "the variations were less pronounced". Which variations were less pronounces.

We will rephrase to "…the variability of the up-scaled FB fluxes were less pronounced.".

Page 15

L 19 – "The good agreement between the two independent approaches" provide a statistical index to support this statement.

We will expand the sentence to: "The good agreement between the two approaches (< 2% difference) …". This difference is much lower than the uncertainty ranges also listed in Table 5.

L28 to 29 – This sentence is a little confusing and needs to be reworded.

We will simplify the sentence for better readability.

L21 – "significant system difference". Over which period of time and shouldn't this difference be expressed per area?

We agree with the reviewer and will replace this value by the emissions per cow and grazing hour of system M and G (see comment to Page 1, line 20 above).

Page 16

L3 to 4 – "e.g. N2O emissions related to the maize production. . .". Could you include values in the literature typical emission factors for corn silage production? These data would allow a fair comparison between the two grazing systems.

It needs to be noted here, that we only considered the N_2O emissions related to the cow excreta on pasture in this study. This is in line with the IPCC concept for emission factors and inventory calculations that generally relate the N_2O emissions to specific N inputs (see Introduction line 8-10). The comparison of different agricultural production systems with full accounting of the production chain (life cycle assessment) is beyond the scope of this study and will be published elsewhere.

As mentioned in the conclusion, the emission difference between the two pasture systems demonstrates the mitigation potential of a N-reduced (N-optimized) feeding strategy. The latter does not necessarily require supplement maize silage feed but may also be achieved by an improved energy to protein ratio of the pasture grass.

L9 – "They are based on". Specify who are "they".

We meant the EFs. We will change that in the revised version of the manuscript.

Page 17

L23 – "emission optimum". What does the word "optimum" mean here? Low N2O emissions?

No, we meant emission maximum. The term "optimum" is often used in this context (e.g. Butterbach-Bahl et al., 2013).

Page 28

Table 5 – "EC integral system emission EC". Do you mean: Integral EC flux system emission?

The entry represents integral emissions for the entire pasture area and the investigated grazing period. In order to prevent confusion and misunderstandings, we will change the units of this type of results (also in the abstract and in the main text) and express them in units of N_2O -N cow^{-1} h^{-1}, which has an equivalent meaning.

Bell, M. J., Rees, R. M., Cloy, J. M., Topp, C. F. E., Bagnall, A. and Chadwick, D. R.: Nitrous oxide emissions from cattle excreta applied to a Scottish grassland: Effects of soil and climatic conditions and a nitrification inhibitor, Sci. Total Environ., 508, 343–353, doi:10.1016/j.scitotenv.2014.12.008, 2015.

Butterbach-Bahl, K., Baggs, E. M., Dannenmann, M., Kiese, R. and Zechmeister-Boltenstern, S.: Nitrous oxide emissions from soils: how well do we understand the processes and their controls?, Philos. Trans. R. Soc. B Biol. Sci., 368(1621), 20130122–20130122, doi:10.1098/rstb.2013.0122, 2013.

Chadwick, D. R., Cardenas, L. M., Dhanoa, M. S., Donovan, N., Misselbrook, T., Williams, J. R., Thorman, R. E., McGeough, K. L., Watson, C. J., Bell, M., Anthony, S. G. and Rees, R. M.: The contribution of cattle urine and dung to nitrous oxide emissions: Quantification of country specific emission factors and implications for national inventories, Sci. Total Environ., 635, 607–617, doi:10.1016/j.scitotenv.2018.04.152, 2018.

Mishurov, M. and Kiely, G.: Gap-filling techniques for the annual sums of nitrous oxide fluxes, Agric. For. Meteorol., 151(12), 1763–1767, doi:10.1016/j.agrformet.2011.07.014, 2011.