Anonymous Referee #1
Received and published: 21 March 2020
GENERAL COMMENTS:
In this paper, Stoy et al. estimate bison enteric emission using the eddy-covariance method, coupled with a footprint model and a cattle location method. This type of approach is under development (Felber et al., 2015; Coates et al., 2017; Dumortier et al., 2017; Prajati et al., 2018; ... all cited in the document) and has the advantages of providing an estimate in the field, integrating the animal to animal variability, having great temporal resolution and the potential to be automated. The current bison herd is small but growing and the application of such a method is especially interesting on a wild species on which the classical methods by metabolic chamber or on-animal tracers are undoubtedly more complicated to apply. Therefore the scientific interest of the paper is proven. However, this method faces technical and methodological difficulties that limit its accuracy. The choice and accuracy of the footprint model, the technical difficulty of automatic tracking of livestock location, the best way to calculate a turbulent flux in non-stationary conditions, and the best way to determine a flux per individual based on turbulent flux and contribution to the footprint are still insufficiently investigated.

However, the paper does not present any significant advances on these points. Geo- location is carried out by manual analysis of images in the visible range, resulting in a restricted dataset of about 170 half hours, making it impossible to study a seasonal or even diurnal evolution of the emissions, a footprint model is arbitrarily chosen and is not compared to other available models and the difficulties related to non-stationarity are not addressed. The paper traces its path, in a pragmatic way admittedly, relying on choices made by other authors and not yet consolidated. An analysis of the dependence of flux on ustar in the absence of bison is proposed, with the aim of identifying a possible filtering criterion for low turbulence, but it is inconclusive in my opinion be- cause of the low magnitude of the fluxes, both of CH4 and CO2. So there is little methodological input. A positive point from this point of view is the sensitivity analysis of the estimation of flux per individual to the precision of geolocation/precision of the footprint model. Some parts are however difficult to follow (e.g. smoothing of positions, see note below).
Some parts of the paper don't seem very useful to me. I am thinking in particular of the justification for the fact that the methane emissions measured do come from livestock (low background flux, i.e. from the soil/plant continuum). This is an essential part of the method, but it seems quite obvious to me for an ecosystem of this type in the winter conditions encountered. The observation of the absence of CH4 flux when the bison are removed from the pasture seems to me sufficiently meaningful and I don't see the point of presenting the absence of dependence of the CH4 flux on abiotic variables (radiation, temperature) to substantiate this observation. I was also hampered by some speculative passages (e.g. mechanisms of flux dependencies to u*, role of excreta, possible diurnal variability) and the perspectives are certainly well written but already known by the community.

Remains the main message that, despite the large uncertainties in the enteric emission per individual, the enteric flux is lower than that of other types of ruminants. It is stated in the introduction that since bison have a grazing behavior that favors nutrient-rich species they may have lower enteric emissions but in this study fodder is provided and is not characterized precisely, neither in terms of quantity nor in terms of quality. The reader therefore has no leads to circumstantiate this result.

I therefore feel that this article is premature and that the critical mass of original and useful information for the community is not reached at this stage. I encourage the authors to expand their dataset to allow for a statistically robust analysis of the quality of the footprint model, of the diurnal flux variability, to investigate methodological limitations in more detail and to propose explanations for low bison enteric emissions. Because I think the topic deserves a new and more robust submission when the above comments will be addressed, I also added below my specific comments, hoping it will help the authors to improve their analysis.
I would also like to point out that the shape of the paper is good, the writing is fluent, the references appropriate and the figures clear.

We largely disagree with this assessment but thank the Referee for the kind notes about the writing of the manuscript. We were generously allowed to measure animals from a privately-owned herd during a select period of the calendar year and did so to the best of our abilities under the reasonable condition that disturbance to the herd be minimized, hence the automated camera approach and three-month sampling period. The method to determine average bison contribution outlined in equations 1-3 is novel and builds upon previous work demonstrating that point- or near point-sources can be captured effectively using eddy covariance (Dumortier et al., 2019; Prajapati and Santos, 2019). The diurnal evolution of the flux estimates was investigated and found not to be significant. We are puzzled that our manuscript, which to our knowledge makes the first measurements of the methane emissions of non-domesticated ruminants, was insufficiently novel. It seems like the caution with which we are interpreting our measurements – for example, exploring u dependencies and methane efflux in the absence of bison – are being mistaken for a lack of novelty. We note that background emissions are a major source of uncertainty of the seasonal course of methane measurements from feedlot studies of cattle (e.g. Prajapati and Santos, 2019) and felt that it was important to study this.*

That being said, we made numerous changes to the manuscript to further improve it. We added the Kljun et al. footprint model as an independent estimate of the footprint with the generous assistance of Natascha Kljun who we added as a coauthor and also added detail about the magnitude of the corrections as noted below; thank you for suggesting that we do so. We comprehensively revised the manuscript in response to reviewer comments and feel that the revision represents a marked improvement.

L20: The uncertainty of 14 gCH4 day-1 bison-1 mentioned in the abstract without any additional comment is, as clearly explained in L194, only including spatial uncertainty (and I have some concerns on this point, see below) and uncertainty due to the flux summation. Information on the huge dispersion on your <f> estimates (standard deviation of 61 gCH4 day-1 bison-1 !) is not even mentioned in the abstract, which is misleading.

Uncertainty was calculated by summing the uncertainty due to spatial location and adding flux measurement uncertainty. The half-hourly uncertainty mostly averages out in the daily sum; consider for example a time series of half-hourly carbon dioxide flux data of an ecosystem during the growing season that follows the expected pattern with light. Taking the average value over the course of a day will have a large standard error but each individual measurement is accurate to within the accuracy of the flux measurement.

L28-70: Nice introduction.

Thank you, we wanted to describe why such measurements are necessary, especially in light of the ongoing success story of bison reintroduction in the North American Great Plains for which we owe a debt of gratitude to Tribal Nations in the US and First Nations in Canada.

L78: The composition of the herd is not specified. Age distribution could strongly influence CH4 emissions.

Thank you for pointing this out; we asked the landowners for the age distribution of the animals and they graciously agreed with a comprehensive table that included sex, weight, and more. We plan on adding a revised version of the table below to a new Supplemental Information section. We also added text to the discussion and a new reference noting the importance of animal age (and especially size) on per-animal methane efflux. Information from the landowner also clarified a question that we had about the number of animals in the pasture. Staff had originally told us that there were 40 animals but records indicate 39, which aligns better with the numbers from counts. We adjusted our location maps accordingly and re-ran the analyses.

SEX	BIRTH YEAR	WEIGHT (lbs.)	Weight (kg)	WEIGHT DATE	PREGNANCY STATUS
F	2010	1030	467	11/16/17	Y
F	2010	924	419	11/16/17	Y
F	2010	944	428	11/16/17	Y
F	2010	1055	479	11/16/17	Y
F	2010	1125	510	11/16/17	Y
F	2010	1050	476	11/16/17	Y
F	2010	1085	492	11/16/17	Y
F	2010	1000	454	11/16/17	Y
F	2010	1250	567	11/16/17	Y
F	2010	1050	476	11/16/17	Y
F	2010	1095	497	11/16/17	Y
F	2010	1015	460	11/16/17	Y
F	2010	976	443	11/16/17	Y
F	2010	958	435	11/16/17	Y
F	2010	940	426	11/16/17	Y
F	2010	1050	476	11/16/17	Y
F	2010	906	411	11/16/17	Y
M	2012	1425	646	11/16/17	
M	2012	1545	701	11/16/17	
F	2014	840	381	11/16/17	Y
F	2014	904	410	11/16/17	Y

F	2016	736	334	11/16/17	
F	2017	242	110	11/16/17	
F	2017	318	144	11/16/17	
M	2017	353	160	11/16/17	
F	2017	367	166	11/16/17	
M	2017	305	138	11/16/17	
M	2017	335	152	11/16/17	
M	2017	325	147	11/16/17	
M	2017	403	183	11/16/17	
F	2017	212	96	11/16/17	
M	2017	458	208	11/16/17	
M	2017	230	104	11/16/17	
M	2017	360	163	11/16/17	
F	2017	279	127	11/16/17	
M	2017	299	136	11/16/17	
M	2017	364	165	11/16/17	
M	2017	278	126	11/16/17	
F	2017	279	127	11/16/17	

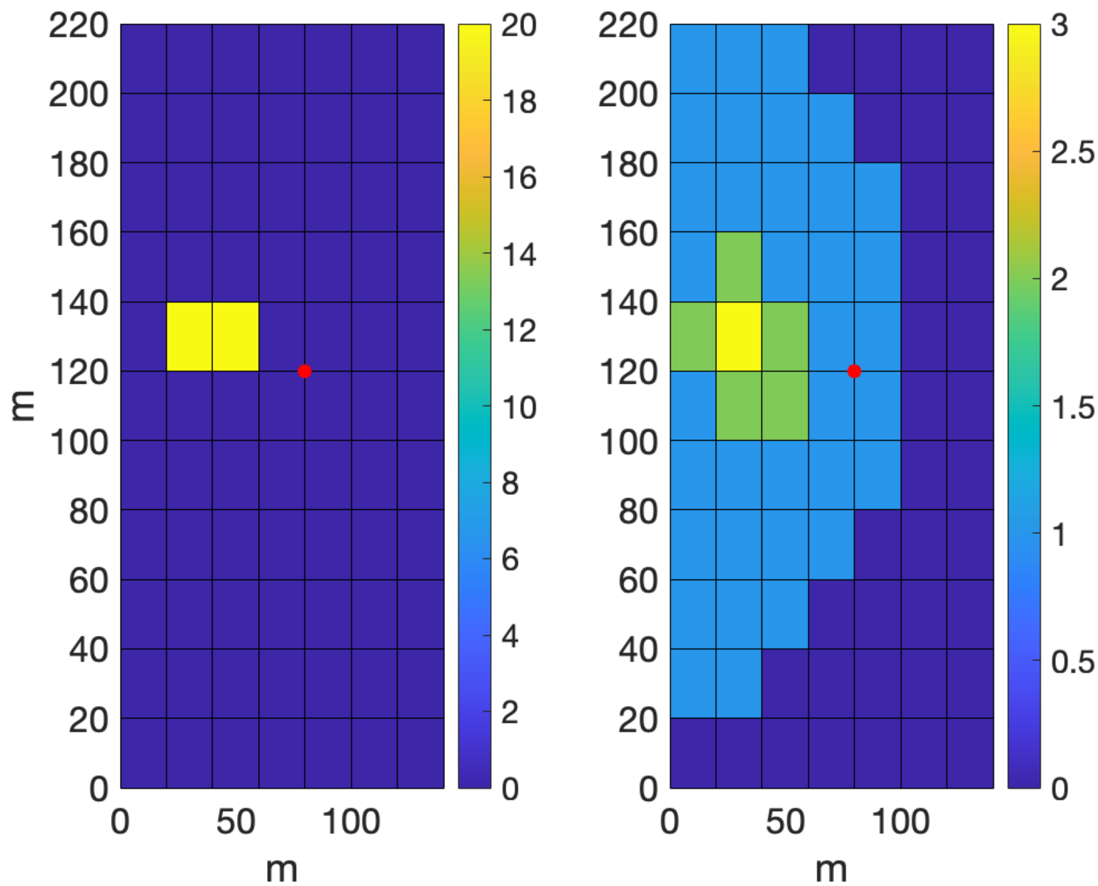
L118: One or two additional lines on spectral corrections would be useful. Lateral separation, reference cospectrum, magnitude of the correction factor.

We added information about the magnitude of the correction factors to CH_4 fluxes (on the order of 14% when bison were present) and now note the LI-7700 which was offset in the horizontal by 22 cm (which is less than the dimensions of the optical path of the instrument at 50 cm) and 0 cm in the vertical.

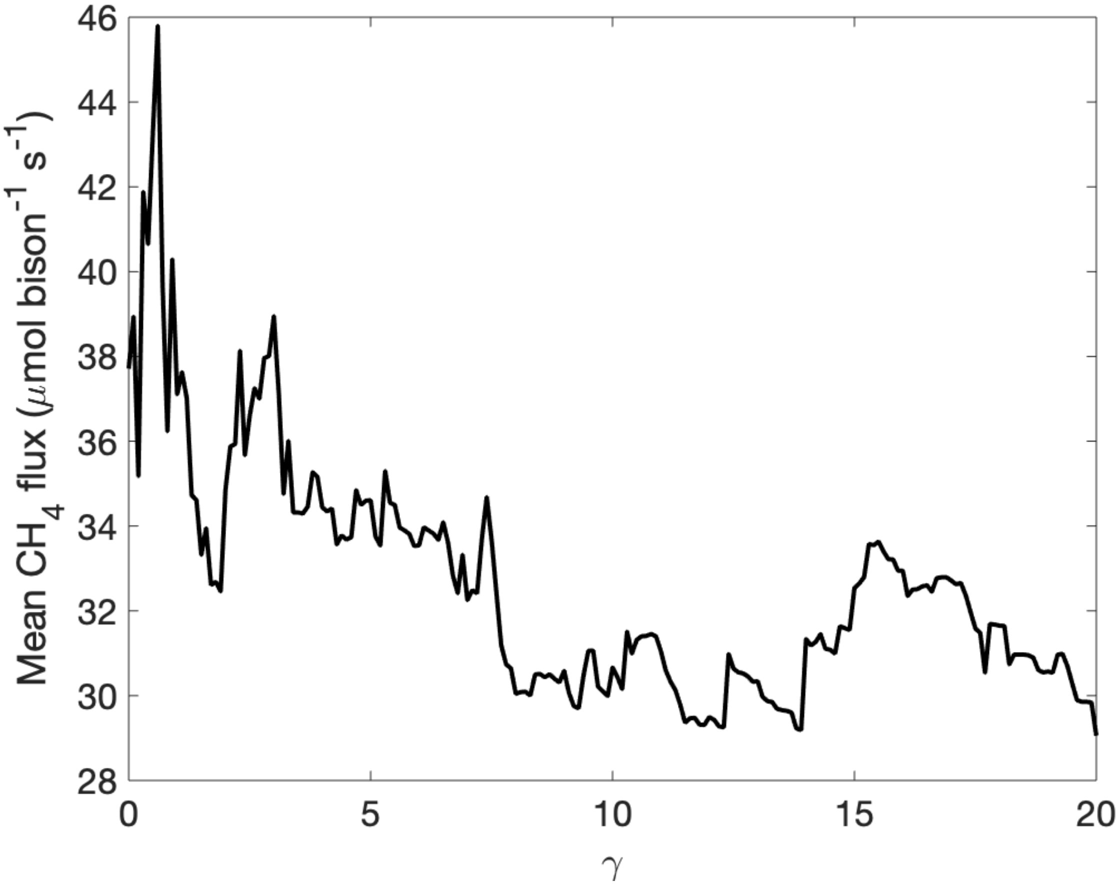
L146-147: Too little information is given on the visual geolocation of bison based on the cameras. All we know is the position of the cameras and "manually attributing bison locations to squares in a 20m grid". How can you assign a distance to the mast with cameras that have no high-angle views and no distance markers in the different azimuths? Are the images from the different cameras combined to triangulate the positions of each individual? And how are the 6 positions averaged at half an hour? The authors propose an uncertainty of 20m on this estimate, which seems small in the absence of details on how to proceed.

Features in the field made it reasonably easy to determine locations (with uncertainty) and we took averages of the six positions for the half-hourly location estimates. Because these and all measurements have uncertainty we decided that it would be appropriate to perform the sensitivity analyses on locations to ensure that our uncertainty is not underestimated. We are more interested here in correctly characterizing uncertainty than pretending that our eddy covariance measurements of non-domesticated ruminants in wintertime in Montana have low uncertainty.

The bison location work has an interesting caveat. It makes little difference to the flux calculation. Take for example an extremely conservative viewpoint of bison location that assumes almost no ability to attribute bison to a particular location outside of a general location on one side of the tower. Such a situation is demonstrated on the right-hand side of the figure below where the Lagrange multiplier is set to 20 for a bison location estimate that happens to be from Jan. 22 at 11 am when bison were clustered in a clump, shown in the subplot below on the left, which is pretty easy to observe (see for example Figure 2 in the manuscript).



If we extend the Tikhonov Regularization analysis to a Lagrange multiplier of 20, representing a very crude visual guess as to the bison location as demonstrated above, the average per-bison methane flux value over the measurement period is about 30 µmol CH_4 bison^{-1} s^{-1} as demonstrated below. This is admittedly much smaller than the derived estimate of about 38 µmol CH_4 bison^{-1} s^{-1}, but we also feel that we can place bison on the landscape using 8 cameras much more accurately than such a wild guess. That being said, the location attribution approach results in uncertainty, and our sensitivity analyses is designed to characterize this uncertainty. Despite this we engaged in the independent footprint estimates as suggested. Initial results are promising and helped us further characterize the uncertainty in our observations.



We undertook the rather comprehensive spatial uncertainty estimates because we were fully aware that the measurements had uncertainty and we sought to be exceedingly honest about the uncertainty in per-animal flux measurements that resulted. Such honesty should not be interpreted as lack of rigor.

L151-155: The paper is not self-standing on the point of "2D Tikhonov regularization". More information is needed so that the reader can understand the concept without having to read the reference assiduously. I do not master this technique but when I see that this spatial smoothing results in redistributing 3 individuals from the group at (x=40-80m,y=80-100m) to a distant group on the example of fig 4, I wonder about its relevance to simulate possible errors of location or footprint function.

We revised section 2.6 to further describe Tikhonov regularization approach used to interpret the bison location estimate with caution. To be honest we were delighted that regularization had the effect of redistributing individuals to different groups (this is entirely due to rounding to full integers), which we felt shared similarities to the tendency of animals to move between different groups as part of their social behavior.

L142: The approach used to determine <f> gives an estimate per half hour. However, the half hours with low contribution to the footprint will show a large dispersion, as this term is used in the denominator in eq. 3. Did the authors try to determine <f> rather by flux regression vs. contribution to the footprint?

We did not determine <f> by flux regression in the manuscript as we believe that this would not fully incorporate the dynamic that exists between bison locations and the flux footprint. (More directly, we feel that it is incorrect to do so and are surprised at this suggestion.) An earlier effort to estimate CH_4 *flux as a function of bison count estimated the effective number of bison in the footprint but the regression was poorly constrained and subsequent work improved the flux footprint location. Instead – and admittedly we should have been clear about this in the original manuscript – we thresholded the dataset to exclude per-animal flux values using outlier identification which we subsequently revised now describe in more detail in the revised manuscript.*

L148-150: I don't think that shifting everything by 1 grid-square cell in each cardinal direction can simulate a systematic error of the footprint model. Proceeding in this way, the impact on the estimation of the mean of the half-hourly <f> will be smoothed. I would understand better if it was systematically shifted by 1 grid-square farther/closer with respect to the mast (modify r in polar coordinates).

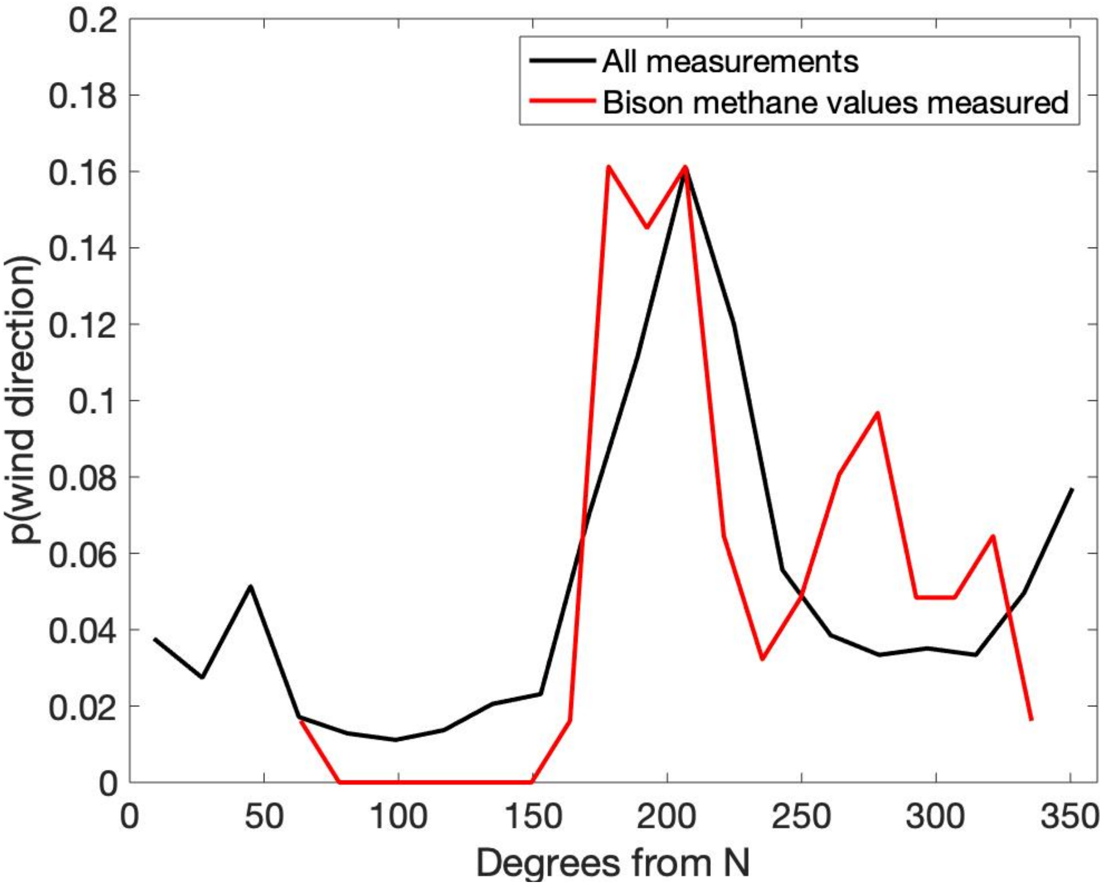
We somewhat disagree, because in our case this is equivalent to shifting the bison distribution in the opposite direction. But we do agree that the inference is reversed in this case and that the flux footprint location likely has less spatial bias than the bison count estimation. We re-analyzed the data by shifting the bison location estimates rather than the flux footprint location estimates; thank you for the suggestion.

L184-187: It is not clear whether Fig. 10 only shows the locations for the 173 half- hourly periods where CH4 fluxes are also available or whether it is the 444 half-hourly periods with camera tracking. The first option seems less misleading to me.

We did not intend to be misleading; rather we wanted to demonstrate the diurnal behavior of the bison to demonstrate to the reader that they usually congregate in directions upwind of the tower. We re-created the figure to only include observations for which fluxes were measured.

L184-187: The forage was not brought in the direction of the prevailing winds. As a result, cattle are often on the sides of the footprint. Is Hsieh's model reliable under these conditions? You suggest that the analytical models were validated for this type of exercise (L249) but it was not the Hsieh model.

The forage was delivered by employees of the private ranch due west of the tower in a place where the field was accessible from the road. Wind most commonly arrived from the southwest, but there is a secondary peak of wind directions from due west during periods when methane measurements were made (see below). Bison tended to congregate to the south, southwest, and west of the tower such that there was considerable overlap between bison and the flux footprint. We were fortunate in this regard because we placed the tower in the center of the field (Figures 1 and 3) as we felt that it was the best practice for flux measurements and bison tended to congregate in the dominant wind directions, noting that the footprint can be rather broad due to *the variance of the lateral wind velocity as demonstrated in Figure 3. To further extend the sensitivity analysis on the flux calculations, we added the Kljun et al. model to the analysis as an independent and additional assessment of the results.*



L196: You should explain how you combine the spatial uncertainty and the uncertainty due to long-term methane flux sums (but annual sums in Deventer et al., 2019, what is the logic behind using it here?)

We combined uncertainty values by summing variances then computing the standard deviation.

L204: The Hogan's publication is 17 years old already. You should rely on more recent literature. Also, the 60 kgCH4 per year per animal for range cattle is an average over very contrasted cattle nature. It would be useful to be more precise.

Older values are not necessarily less reliable but we added newer references including Prajapati and Santos, 2019, which was published as we were preparing the manuscript and escaped our initial notice, thank you for the suggestion.

L238-241: not convinced by the statistical reliability of this assertion. Since it seems to be the case for you too, Figure 13 should be removed.

We spent quite a bit of time trying to interpret if methane efflux differed over the course of the day as a function of their preferred feeding times but results were not conclusive. We removed Fig. 13 and now simply note in the text that significant diurnal methane flux patterns were not observed.

Fig 5: Is it really necessary to show (and use in statistical analyses) both SW and Rnet?

From the observations these variables differ rather strongly due in large part to the brightness of the snow and the differences between the snow surface temperature and sky temperature in the longwave. That being said, we do not use net radiation in subsequent analyses and removed the subplot to make the figure less busy.

TECHNICAL CORRECTIONS:
L191-193: the range 36-44 is repeated twice. Probably a typo?

Thank you for pointing this out. We looked into it and it happens that both approaches independently arrived at the same range. We assume that this is due to chance.

L196: gCH4 bison-1 day-1 instead of gCH4 m-2 day-1 !!!

This is correct, thank you for pointing out this error.

L211: 'negative' instead of 'positive'

Referee #2 also noted this error and it is now corrected, thank you for the careful read.

L494: something is wrong in this sentence.

The sentence was unnecessarily wordy. We re-wrote it to state 'Figure 3: An eddy covariance flux footprint calculated following Hsieh et al. (2000) and Detto and Katul (2006) at 1 m resolution for a single 30-minute interval superimposed on the study field (Figure 1).'

Fig 6: For better readability, the tower should be the origin of the spatial scale. Also in fig 10.

This is an interesting point and we carefully considered it but decided to keep the figure as is because it aligns with the grid in Figures 1 and 3 that we used to attribute bison locations. We did change the font size of the figure to have more information along the x-axis.

Fig 7: add ticks for the x scale.

We agree that tick marks on the x axis are an improvement and added these along with standard error bars as recommended by Referee #2.

Fig 9: ustar should be in m s-1
Our apologies, this is clearly a typo on our part. The figure has been revised.