Review for “Methane efflux from an American bison herd”

General comments

The manuscript “Methane efflux from an American bison herd” from Stoy et al. presents winter CH4 fluxes from a bison grazing system combined with a flux footprint analysis to estimate average CH4 fluxes per animal and day. It addresses the interesting scientific question on the magnitude of bison emissions. The data is presented in a clear structure and easy-to-follow writing style. The manuscript uses methods which have been shown with varying success elsewhere (e.g. Felber et al., 2015; Coates et al., 2017). While other authors used also automatic GPS tracking (e.g. Felber et al 2016 in AEE) the authors manually attributed the animals to a raster. Acknowledging the difficulty to assess a system of wild animals, the method used can be seen as useful first step to quantify bison emissions. A main methodological issue is that the flux uncertainty is underestimated. Knowing that the different footprint models give very different results on which your approach relies upon – to better depict the uncertainty, it would be useful to analyze sensitivity of the CH4 flux per animal to different footprint models in order to include this uncertainty in the presented SE. The study lacks conclusiveness regarding the bison emission estimate: If the results were robust - What was the reason for the low CH4 emissions from bisons compared to average cattle emissions?

Thank you for the insightful comments, addressing them improved the manuscript. We added the Kljun et al. footprint model to further characterize uncertainty as suggested. A side-by-side (or similar) comparison between cattle and bison systems would be necessary to understand the mechanisms causing any discrepancy, and we hope that the present manuscript helps justify such an extensive undertaking.

Specific comments

L 21 “Emission estimates are subject to spatial uncertainty in bison location measurements and the flux footprint, but from our measurements there is no evidence that bison methane emissions exceed those from cattle. We caution however that our measurements were made during winter and that evening measurements of bison distributions were not possible using our approach.“ The sentence does not make sense. “but” indicates a contrast, while no significant differences are exactly a result of high spatio- temporal variability/and considerable measurement uncertainty. Please rather give the exact numbers ± SE for both estimates, for so the readers get an idea of what it means that no differences were found.

We removed the passage for clarity because no direct measurements of cattle were made. Finding adjacent or proximal bison and cattle grazing systems to measure has been an ongoing challenge, and one that we hope to address in future research.

L 25 Eddy covariance is a promising technique for measuring ruminant methane emissions in conventional and alternate grazing systems and can be used to compare them going forward. RC: The sentence is not really saying much that was not known before. Rather state a concluding sentence from what you found.

We feel that the passage as written is accurate because eddy covariance has not been used to measure methane efflux from non-domesticated animals before. Because our study is in part a proof-of-concept that is important to demonstrate feasibility for future research efforts on non-

domesticated ungulates, we made the last line of the abstract more directed and now write, 'Our observations point to the need for direct comparisons of methane emissions from conventional and alternate grazing systems using eddy covariance and demonstrate the potential for using eddy covariance to measure methane efflux from non-domesticated animals.'.

Introduction
RC: L43: Add one sentence about: What is known about methane emissions from energy-dense/high-quality versus low-energy/low-quality grass for cattle?

We added 'and feed quality (Hammond et al., 2016)', thank you for the suggestion.

L46: "Methane is a highly potent greenhouse gas and has about 3.7 times the global warming potential of carbon dioxide on a per- mole basis (Lashof and Ahuja, 1990)." RC: I guess you overlooked some major updates since the nineties – please cite the most recent IPCC report (2014). The number(s) there are considerable higher...

We deleted the passage because these comparisons rely on a subjective time window and the readership of Biogeosciences is familiar with the importance of methane as a greenhouse gas.

L49: Between 30 and 40 percent of anthropogenic methane emissions are due to enteric fermentation in livestock

We clarified this passage to state 'current' anthropogenic methane emissions.

L60 "The important role of bison to past methane fluxes suggests that current their role in the global methane budget must be understood as their populations increase." The sentence does not make sense, improve spelling/grammar.

Thank you for the suggestion the passage was re-worded for clarity.

L 63: 30 L per kg dry food intake – how does this compare to measurements from cattle? The number is not very meaningful without comparison as a reference

These are simply the results presented by Galbraith et al. who did not measure cattle in their study. In the revised manuscript we cite cattle values from Hammond et al., 2016 who used a similar technique and found nearly identical values 16.5 g methane / kg dry matter intake (= 29.8 L methane / kg dry matter intake) when feeding dairy cattle a high maize silage; thank you for suggesting that we dig into this topic further.

Methods
If you provide hay, how are the feeding values typical for what they would eat otherwise? I would guess the hay represents rather an average, not particularly species selected to be nutrient-rich.

The landowners provide supplemental hay from a nearby field. Upon further request, we were sent extensive tables of the hay nutrient content and feed and we will summarize these as *supplemental material noting that bison were also free to graze within the pasture. In the revision we will provide a version of the following nutrition information and feeding tables. We assume that the forage is of similar quality to whatever pasture grasses the bison are eating, but we were unable to confirm this independently and the bison fed rather vigorously on the supplemental hay.*

Table 1: Composition of the first cut and second cut hay provided as a supplement to the study bison herd.

Variable (% unless otherwise noted)	First cut	Second cut
Crude Protein	9.7	17.2
Acid detergent fiber	47.9	38.3
Total digestible nutrients	48.9	59.7
Calcium	0.8	1.51
Phosphorus	0.2	0.21
Magnesium	0.21	0.32
Potassium	1.92	2.06
Sulfur	0.15	0.32
Sodium	<0.011	0.028
Zinc (mg/kg)	14	15
Iron (mg/kg)	66	61
Manganese (mg/kg)	60	56
Copper (mg/kg)	7	9

Table 2: The schedule of bail delivery of first cut and second cut hay to the bison pasture.

	First cut (number of bails)	Second cut (number of bails)
1-Nov	2	2
3-Nov	2	2
5-Nov	1	1
6-Nov	2	2
8-Nov	2	1
10-Nov	2	1
12-Nov	1	1
13-Nov	1	1
14-Nov	1	1
15-Nov		2
16-Nov	1	1
17-Nov	2	2

20-Nov		2
22-Nov	1	2
25-Nov		2
27-Nov	2	2
29-Nov		2
1-Dec		2
3-Dec		
5-Dec	2	2
8-Dec	2	2
12-Dec		2
15-Dec	2	2
19-Dec	2	2
21-Dec	2	2
26-Dec	2	2
28-Dec	2	2
31-Dec	2	2
2-Jan	2	2
5-Jan	2	2
8-Jan	2	2
11-Jan	2	2
15-Jan	2	2
18-Jan	2	2
22-Jan	2	2
26-Jan		2
27-Jan	2	
29-Jan	1	1
31-Jan	1	1
3-Feb	2	2
6-Feb	2	2
10-Feb	2	2
14-Feb	2	2
19-Feb	2	2
22-Feb	2	2
26-Feb	2	2

The methodology for deriving bison location is not clearly described. The perspective of the cameras gives a highly skewed picture. From the description the bison attribution to a grid-cell is not comprehensible. Please describe precisely what you did.

This was a labor-intensive process. We interpreted each five-minute period from multiple cameras and used visual cues in the field (like trees in the background) to note the locations of the animals. Fortunately they were usually congregated in a group which made them relatively easy to place, but wanted to be extremely conservative with our location estimates and their impact on per-animal fluxes, hence the sensitivity analyses.

How can you justify a shift by a grid-cell of 20 m in each direction is sufficient to represent spatial inaccuracies?

Per the response to Referee 1, we were somewhat surprised to find that the precise spatial representation did not make a large difference in per-animal flux estimates. Roughly associating bison to general areas around the tower (following the figure below for one particular half-hour) decreased the per-animal flux estimate by only about 25%. We could be even more conservative with our uncertainty analyses but feel that the Tikhonov Regularization analysis accounts for spatial uncertainties and also provides realistic bounds on per-animal flux values that could be generated. We decided to shift the maps of bison location as an additional check on the sensitivity of the flux values to bison location to provide an even more conservative estimation of uncertainties. We feel that the resulting flux values honestly represent the inherent uncertanities in our analysis.

Please explain to the reader the two-dimensional Tikhonov Regularization (& Lagrange multiplier) in a methods paragraph.

We describe Tikhonov Regularization in more detail in the revised manuscript by expanding section 2.6.

The methods section on the flux calculations could be more specific, i.e. state the respective thresholds and parameters used.

We feel that we were reasonably clear about the flux calculations having indicated spike thresholds but we agree that we could have been more clear about necessary filtering post-processing. We revisited the logical thresholds that we applied to the original dataset after applying the Kljun et al. (2015) flux footprint model and increased the upper limit to 300 micromoles CH_4 m^{-2} $bison^{-1}$. Doing so made a small change to average flux values that we feel more confident in because of very intermittent data and large gaps in the histogram at values greater than 300 micromoles CH_4 m^{-2} $bison^{-1}$.

The paper would benefit from some numbers indicating: How many datapoints are actually available with e.g. > 20 bisons placed in the area of 60% flux contribution footprint area.

This is an interesting question but we did not feel that it would lead to clarity as each pixel in which bison are located represents a small contribution to the integrated footprint area and the per-bison methane contribution that it represents is embodied in the calculation in equations 1-3.

Results

It necessary to state that winter methane fluxes in the system without bisons are insignificant, as this is a basis for the whole calculation. Still, there are many words spent on this in the results and discussion, I think that this adds not much to the content of the paper.

We agree and took care to minimize the discussion of methane efflux in the absence of bison, but also felt that it was important to describe given potential methane sources in a field that is frequented by wild ungulates (who can jump the fence) and the nearby river (that is not in the dominant wind direction. We still wanted to be very diligent in noting that the field otherwise is near-neutral with respect to methane efflux. We are not sure why that the cautious approach that we take throughout the manuscript is deemed superfluous.

Fig. 7: include the daily variability of fluxes

Previous versions of the text included error bars that made the trends difficult to distinguish and we presented the median rather than the mean to emphasize the bulk of the trends. We worked to create a version that includes error bars and that is hopefully easy to visually interpret and also included x-axis ticks as recommended by Referee #1.

L211 negative not positive

Thank you for noting this error.

In the highly skewed distribution (Fig 11), it is getting obvious that the SE does not represent well the uncertainties. Consider reporting quantiles of the distribution which then reflect the higher uncertainties towards higher CH4 flux values.

We feel that showing the full probability distribution is the most accurate way of demonstrating the range of values. One might argue that a box and whisker or violin plot may be more appropriate for Figure 7, and we would be inclined to agree, but such a plot would be too busy for the human eye to easily render. We also did not want to burden every value placed with maxima, minima, ranges, and the like and we further point out that we were careful to ensure that negative flux values remained in our per-bison flux estimates, rather than thresholding the values at zero, which can bias the full uncertainty distribution of the observations.

It would be useful and interesting to repeat the measurements with the fodder source placed in the major footprint area.

Bison and the flux footprint both tended to reside in the south, southwest, and west ends of the pasture. This is a major reason why we chose the particular experimental design. It would be an interesting additional experiment to place feed within the footprint, but this might amount to flux chasing. Bison are powerful and unpredictable animals and entering their enclosure would be very risky (and certainly not allowed by the University). Fodder was delivered by the employees of the landowner over the fence from a safe distance.

From Fig 3 and Fig 6 it becomes clear how little overlap there is between bison presence in the footprint. How would the flux estimates look like if you just choose the occasions when the joint presence of many bisons overlaps with the core (i.e. 50% flux contribution) footprint area for a certain time? Such an analysis could enhance the understanding of how robust your estimate is.

Figure 3 represents a half-hour period and Figure 6 the aggregated flux footprint, which lies predominantly to the southwest. Bison tended to aggregate to the west such that there was considerable overlap between bison and footprint distributions. We do not know how this conclusion was arrived at given that the footprint and bison favored the areas west, southwest, and south of the tower. We recreated the figures to demonstrate the overlap between bison and footprint given that we carefully designed the experiment to ensure reasonable overlap between the footprint and bison distributions.

Discussion
Give an approximate estimate of the bulk uncertainties inherent to the flux calculations in the discussion section.

We feel that we did this in the opening paragraph of the Discussion.

It remains unclear if the low CH4 fluxes for bison fluxes is a result of methodology (spatial distribution, flux footprint uncertainty, non-stationary conditions) and possibly (but probably of much less importance) also other confounding factors (fodder composition).

We agree but could not test bison methane efflux with respect to diet directly without a calorimeter (and permission from the landowner and University to make such a measurement, neither of which would be likely to be granted and further the animal may have to be sedated and/or at a lower metabolic state to be in a box, resulting in measurement bias). We suspect that a major reason for low methane fluxes is due to energy conservation during winter and hope to confirm this by securing grant funding for a larger study to do so. The seasonal cycle of cattle methane efflux is apparent in Prajapati and Santos (2019) and other references who often assume that the seasonal variability may be due to changes in background sources in their feedlot system. We are curious to know how seasonal metabolic effort impacts CH_4 *efflux and expanded the discussion of this topic in the revised manuscript.*

In the discussion, it is necessary to more specifically elaborate on why bison CH4 emissions should be that low, what can be reasons/mechanisms behind it?

We were hesitant to speculate on the reasons for the relatively low per-animal methane efflux but do note that they are rather similar to Prajapati and Santos (2019) and other values from cattle in winter. We note this more explicitly in the revised manuscript. As noted in the above comment we suspect that wintertime energy conservation is a dominant reason and we are interested in exploring seasonal variability in methane efflux further.

The methodological issues seem to dominate the outcome of the paper and I lack of confidence in the estimated uncertainty.

We disagree. We treated methodological challenges with an abundance of caution and state this extensively in the text. We included two sensitivity analyses with respect to the footprint analysis *that is now extended to include an independent footprint model. We feel that this exceeds the uncertainty analyses of most eddy covariance-based studies.*