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Atmospheric Measurement Techniques Discussions

Interactive comment on "On-farm beef cattle methane emissions measured with tracer-ratio and inverse-dispersion modelling techniques" *by* Mei Bai et al.

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Dear reviewer (Anonymous Referee #2), Re: Revision of manuscript Number: AMT-2020-445, Title: Beef cattle methane emissions measured with tracer-ratio and inverse dispersion modelling techniques

We thank your positive feedback on the manuscript. We have addressed the comments thoroughly, our response to every issue raised is given point by point below.

1. Two different laser instruments were used, as well as the comparison of two different measurement techniques. The rationale for this is not very well explained, and

needs expanded upon. Agree. In the revised manuscript, the information has been added in the Introduction section as well as the methods and materials. 2. The IDM method is barely explained, and really only by reference to previous papers and the software web site. This needs at least a brief description and some key details. Agree. we have added the information in the revised manuscript. Pages 6-7, lines 203-210. "Herd CH4 emissions were calculated using the IDM technique (Flesch et al., 2004). This micrometeorological technique estimates emissions based on the enhancement of CH4 measured downwind of the animal pen. The link between the concentration enhancement and the pen emission rate is calculated using an atmospheric dispersion model. The freely available software WindTrax (www.thunderbeachscientific.com) is used for that calculation. WindTrax combines a backward Lagrangian stochastic dispersion model with mapping software and takes as input: the upwind and downwind CH4 concentration measurements, wind information from a sonic anemometer, and a map of the pen and gas sensor locations. General information on WindTrax applications is given in Flesch and Wilson (2005)." 3. How were the uncertainties calculated? This is important, and values needs to be included in Table 1. Statistical testing is not relevant, and reference to p values should be removed. Agree. We have added the standard error of each mean values. The standard errors have been added in the Table 1. Also removed the p value.

4. The advantage of the IDM method versus the tracer method is not very clear. The latter is simple enough to be explained in one equation. It seems to be the logistic problem of releasing the tracer versus the computational task and assumptions of running WindTrax. Scope for discussion at least. We agree with the reviewer's comments. We have added the information of tracer-ratio and IDM method to the revised manuscript. Page 2, lines 38-51.

5. Discussion - the agreement of the two method seems to depend on the spatial distribution of the animals, which comes down to the vagaries of the pen size and animal density. So a single 7-day experiment is not grounds to say that the agreement

will generally be good. Does the spatial distribution of the animals affect both methods similarly? If not, why not? This needs expanding. In the manuscript, we have explained the good agreement between the IDM and tracer-ration technique. Page 10, lines 306-316. “When previously applied to cattle environments, some recent IDM studies have monitored animal positions assuming this information is critical to getting accurate calculations (e.g., McGinn et al., (2011)). Alternatively, other studies constrained animal locations by fencing to minimize the errors when animal positions were not monitored (Flesch et al., 2016). However, our IDM calculations assuming cattle were evenly distributed across the paddock were nearly identical to the tracer-ratio results that implicitly include the impact of animal positions. This indicates that IDM studies like ours can use the much simpler approach where the whole paddock is treated as a gas source, and animal positions need not be monitored. This seems to confirm a similar finding from McGinn et al. (2015). The effect of this simplification on measurement accuracy is likely to depend on animal density and the size of the paddock. For example, the measurement of a small number of animals in a large paddock is likely to be very sensitive to the exact animal positions. But in the modest sized paddock studied here (and in McGinn et al., (2015)) this is not the case.” Given our experiment configuration, constant easterly winds, absence of light winds, and good quality data that 80-90% of measurement data is useful and sufficient to calculate the fluxes, we are confident with our results based on 7-day measurement.

Specific points: l 72: the tracer-ratio technique is indeed simple, but cannot be considered "true". The uncertainty associated with its estimates needs to be quantified. The point is presumably that these uncertainties are smaller than the IDM method, but this needs to be demonstrated. E.g. how predictable is the N2O release rate? The authors say this has to be corrected for temperature dependency, but presumably this is established in lab tests?

The canister pressure is correlated with the ambient temperature. Prior to the field study, temperature dependent factor associated with canister release rate was tested

in the laboratory, and CO2 was used as the tracer gas due to its low cost. CO2 flow rate was tested at a range of controlled temperature to determine the CO2 release rate temperature dependent factor. Because N2O and CO2 have the same molecular mass, we assumed that N2O and CO2 disperse in a similar path in the atmosphere and have the same characteristic temperature dependence. The N2O flow rate calculation consists of three steps:

1) The N2O flow rate of each canister was calculated following Bai (2010) (Eq.1): QN2O (t) = Q0 + ÉŚ T (t) (1) Where QN2O (t) is the individual canister flow rate (g h-1) at temperature T (°C), t = time, T = temperature °C at time (t), Q0 is a constant canister flow rate at temperature 0°C, g h-1, ÉŚ is the N2O flow rate temperature dependent factor, g h-1 °C-1. The temperature was measured at 5-min intervals. 2) The integrated N2O flow rate over the total release time (RT, ∼24h) equals the mass loss of N2O gas (ΔmN2O, g) (Eq.2): Q0 = (ΔmN2O /RT) – (Σ (ÉŚ T (t)))/RT (2) Where ΔmN2O = WN2Ostart -WN2Oend The mass loss of N2O was determined by the initial and the end weight of the canister (g), WN2Ostart, WN2Oend, respectively. The integrated N2O flow rate of each canister was then interpolated to a 15-min interval flow rate using linear interpolation function (Igor 6.3.7.2). The total N2O flow rate of the 16 canisters (QN2O) was used for the CH4 emission rate calculation. 3) Following the procedure described in Bai (2010), Griffith et al. (2008), and Jones et al. (2011), the herd emission rate of CH4 was calculated (Eq.3): QCH4 = QN2O*(ΔCH4/ΔN2O) *(MCH4/MN2O)/Nanimal (3) Where QCH4 is the CH4 emission rate, g head-1 h-1, QN2O is the integrated N2O flow rate of total canisters in the animal backpacks, determined by mass loss of N2O at canister temperature T and release time t, g h-1, is multiplied by 24 to calculated g head-1 d-1. The ΔCH4 and ΔN2O parameters are the CH4 and N2O concentration enhancements (above the local background level) measured downwind of the animal pen using the OP-FTIR spectrometers, MCH4 is the molecular mass of CH4, 16 g mol-1, MN2O is the molecular mass of N2O, 44 g mol-1, Nanimal is animal number, 16. l 78:define exactly what Qch4 is, with units. QCH4 refers CH4 emission rate, g head-1 h-1.

l 110: could the data collected while the animals were absent be shown, to demonstrate the noise/sensitivity? This provides a neat control period with zero emission. We used this period to calibrate OP-FTIR and OP-laser. 1) During the study we collected a number of air samples using volumetric flasks (600 mL). Samples were spaced along each measurement path and taken when animals were absent from the pen. These samples were later analysed in the laboratory using a closed-path FTIR spectrometer (Griffith, 1996) and the CH4 and N2O values were used to cross-calibrate the two OP-FTIR sensors. 2) Samples were also collected (20 mL) into evacuated 12mL vials (Exetainer®, Labco Ltd., Ceredigion, UK) at 2 min intervals to get 15-min average concentrations for the period from 9:15 – 9:30 am. This was a period when the cattle were not in the paddock. The samples were analyzed by the gas chromatography (GC)(Agilent 7890A, Wilmington, USA) at the University of Melbourne laboratory. Three positions were sampled: 1) directly west of the paddock along the laser/FTIR line, 2) near the laser, southwest of the paddock, and 3) far south of the paddock along the southerly laser line. Winds were from light and from the east. We hoped the CH4 and N2O concentrations at these positions would be similar (as cattle were absent) and would provide the basis for calibration of the lasers and FTIRs. The sample analysis showed that CH4 was elevated at the location immediately downwind of the paddock (CH4 = 1.88 ppm). The other two locations had average values of 1.75 and 1.80 ppm – reasonable background levels. Therefore these two concentration measurements can be averaged (C = 1.77 ppm) and used to calibrate the lasers and FTIR on the paths not downwind of the paddock: the 1.77 ppm value was used to calibrate the scanner laser on the south-pointed path, and to calibrate the SW FTIR on the east-pointed path, and the NE FTIR on the south-pointed path. This information are described in the revised manuscript. l 131: how big is the sensor drift? Is this a large uncertainty? The drift was between 5% to 15% with larger drift of OP-Laser.

l 144: touchdowns - the whole Lagrangian particle idea needs to be explained. We added the information of IDM technique in the revised manuscript. Pages 6-7, lines

203-210. “Herd CH4 emissions were calculated using the IDM technique (Flesch, Wilson, Harper, Crenna and Sharpe, 2004). This micrometeorological technique estimates emissions based on the enhancement of CH4 measured downwind of the animal pen. The link between the concentration enhancement and the pen emission rate is calculated using an atmospheric dispersion model. The freely available software WindTrax (www.thunderbeachscientific.com) is used for that calculation. WindTrax combines a backward Lagrangian stochastic dispersion model with mapping software and takes as input: the upwind and downwind CH4 concentration measurements, wind information from a sonic anemometer, and a map of the pen and gas sensor locations. General information on WindTrax applications is given in Flesch and Wilson (2005).” l 146: spec.max? Spec. max refers spectral signal intensity.

l 149: why was the diel cycle used? What is driving the diel cycle in methane emission? Production rate should be constant, but emission will be affected by feeding behaviour, Or is this cycle a measurement artefact? This needs explaining. Other gap-filling methods might be better e.g. smoothers such as GAMs. We have several literature examples where emission rate observations have been grouped by time-of-day to come up with an ensemble 24-hour emission curve. For example, Bai et al., (2015), Loh et al., (2008) and Laubach et al. (2013). We used Generalized Additive Models (GAM) fitted to the time series of gas emission to impute missing measurements (see Fig. A1 below) (Bai et al., 2020). Note that longer periods of missing data combined with a higher residual error component and a higher wiggliness in the GAM smoother inflates estimate uncertainty for the IDM-Laser method. Insert Figure A1.

l 171: Yield needs to be explained. Methane yield refers g CH4 kg-1 dry matter intake (DMI).

l 216: This question is not answered very clearly. The authors seem to find no reason, except the IPCC value should perhaps have wider uncertainty bounds on it. Agree. We changed the sentence to be “This suggests that IPCC estimates may have larger uncertainties.” Page 11, line 332.

References Bai, M., 2010. Methane emissions from livestock measured by novel spectroscopic techniques. PhD Thesis Thesis, University of Wollongong, 303 pp. Bai, M., Flesch, K.T., Trouvé, R., Coates, T.W., Butterly, C., Bhatta, B., Hill, J. and Chen, D., 2020. Gas Emissions during Cattle Manure Composting and Stockpiling. J. Environ. Qual. , 49: 228-235. Bai, M., Flesch, T., McGinn, S. and Chen, D., 2015. A snapshot of greenhouse gas emissions from a cattle feedlot. J. Environ. Qual., 44(6): 1974-1978. Flesch, K.T., Baron, V., Wilson, J., Griffith, D.W.T., Basarab, J. and Carlson, P., 2016. Agricultural gas emissions during the spring thaw: Applying a new measuremnt technique. Agric. Forest Meteorol., 221: 111-121. Flesch, T.K. and Wilson, J.D., 2005. Estimating tracer emissions with a backward Lagrangian stochastic technique. In: J.L. Hatfield, J.M. Baker and M.K. Viney (Editors), Micrometeorology in agricultural systems. American Society of Agronomy, Inc. Crop Science Society of America, Inc. Soil Science Society of America, Inc., U.S.A., pp. 513-531. Flesch, T.K., Wilson, J.D., Harper, L.A., Crenna, B.P. and Sharpe, R.R., 2004. Deducing ground-to-air emissions from observed trace gas concentrations: A field trial. J. Appl. Meteorol., 43: 487-502. Griffith, D.W.T., 1996. Synthetic calibration and quantitative analysis of gas-phase FT-IR spectra. Appl. Spectrosc., 50: 59-70. Griffith, D.W.T., Bryant, G.R., Hsu, D. and Reisinger, A.R., 2008. Methane emissions from free-ranging cattle: comparison of tracer and integrated horizontal flux techniques. J. Environ. Qual., 37: 582-591. Jones, F.M., Phillips, F.A., Naylor, T. and Mercer, N.B., 2011. Methane emissions from grazing Angus beef cows selected for divergent residual feed intake. Anim. Feed Sci. Tech., 166: 302-307. Laubach, J., Bai, M., Pinares-Patiño, C.S., Phillips, F.A., Naylor, T.A., Molano, G., Cárdenas Rocha, E.A. and Griffith, D.W.T., 2013. Accuracy of micrometeorological techniques for detecting a change in methane emissions from a herd of cattle. Agr. Forest Meteorol., 176(0): 50-63. Loh, Z., Chen, D., Bai, M., Naylor, T., Griffith, D., Hill, J., Denmead, T., McGinn, S. and Edis, R., 2008. Measurement of greenhouse gas emissions from Australian feedlot beef production using open-path spectroscopy and atmospheric dispersion modelling. Aust. J. Exp. Agr., 48: 244-247. McGinn, S.M., Flesch, T.K., Coates, T.W., Charmley, E., Chen, D., Bai, M. and Bishop-Hurley,

G., 2015. Evaluating dispersion modelling options to estimate methane emissions from grazing beef cattle. J. Environ. Qual., 44: 97-102. McGinn, S.M., Turner, D., Tomkins, N., Charmley, E., Bishop-Hurley, G. and Chen, D., 2011. Methane Emissions from Grazing Cattle Using Point-Source Dispersion. J. Environ. Qual., 40(1): 22-27.

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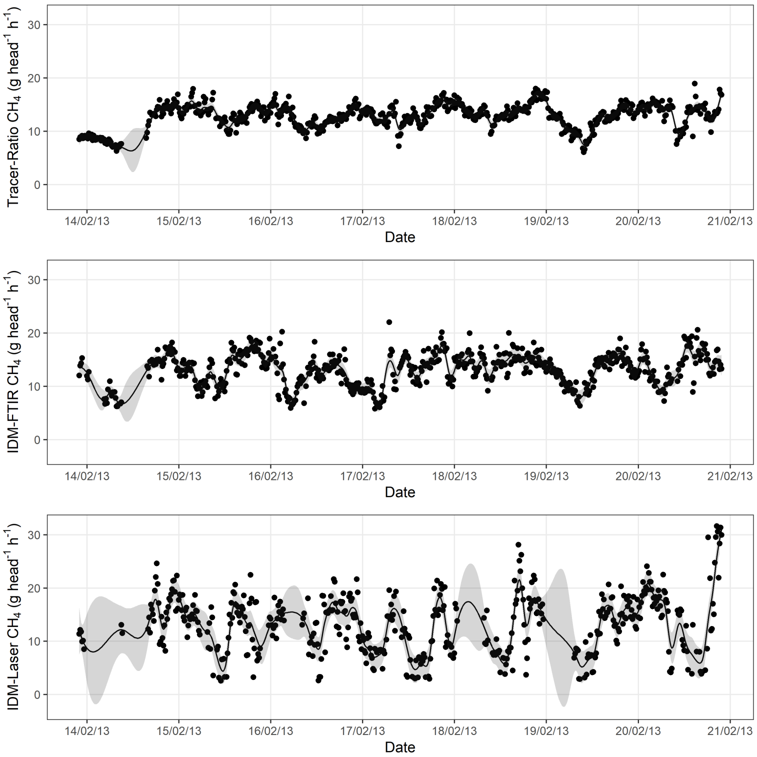

Fig. 1. Figure A1: Time series of CH4 emissions measured using the Tracer-Ratio, IDM-FTIR, and IDM-Laser methods. Black dots show the 15 minutes measurements. The solid black line shows the mean value of gas