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Title: Evaluating the feasibility of using downwind methods to quantify point source oil and gas emissions using continuous monitoring fence-line sensors

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March 18th, 2025

Dear Dr. Lashgari,

We appreciate the time and effort you dedicated to providing feedback on our manuscript. We have closely followed the suggestions and have revised the manuscript accordingly. We believe the revisions have improved our manuscript and that it is ready for publication. We have listed the original comments and our response in blue below for our reply to comments. All figure numbers, tables, and lines refer to the updated manuscript. Data for reviewers' is available at Reviewer URL: http://datadryad.org/stash/share/7s42bajRb2czaY9hr6NbTKDAolCWZ_pNrty0o54qXBE. The authors would also like to emphasis that the paper aims to inform real-world oil and gas fence-line sensors deployment on feasible quantification approaches as oil and gas emissions can be complex (multiple sources could be emitting at the same time). As a result, we have accordingly modified our manuscript and title to "Evaluating the feasibility of using downwind methods to quantify point source oil and gas emissions using continuous monitoring fence-line sensors".

We look forward to hearing from you.
Please find our detailed responses below.

Yours sincerely,

Mercy Mbua (corresponding author)

and co-authors: Stuart N. Riddick, Elijah Kiplimo, Kira B. Shonkwiler, Anna Hodshire and Daniel Zimmerle

General comments

This manuscript compares three methods of point source emissions quantification (eddy covariance-EC, aerodynamic flux gradient method-AFGM, and the inverse Gaussian plume method-IGPM), investigating the performance of these methods in quantifying emissions for known gas release rates and evaluating uncertainties involved in the estimates. Although this is a timely topic, I recommend a revision to the current form of the manuscript before its publication. Here are my comments:

Authors response

Thank you for reviewing our paper. We have accordingly addressed the concerns in the specific comments below. We have also added the backward Lagrangian point-source quantification model.

Comment 1

Please provide a sufficient explanation of the three employed approaches. For instance, it is unclear how the inferred rates are estimated in Figures 4-6. Providing sufficient details about the different modeling choices can make significant improvements to the paper. For instance, the equation for the inverse Gaussian plume model (equation 7) only applies to a single source. It will be helpful to explain how this approach is used to model multiple release scenarios. Another example is the definition of the downwind distance (x) under such conditions.

Authors response

Thank you for your comment. We have revised our manuscript accordingly. In this study, we evaluated the models for single-release single-point emissions (single emission at the site level) and multi-release single-point emissions (multiple emissions at the site level, but the mast was downwind of one source. For the eddy covariance and aerodynamic flux gradients models, to estimate footprint of each source when there is more than one source in wind sector range, more than one sonic anemometer is needed to solve the footprint equation as calculated by Dumortier et al (2019). In this study, we had a single sonic anemometer. The backward Lagrangian stochastic model in WindTrax can only simulate one upwind source at a time. As a result, we limited our comparison to these two test scenarios.

Changes to Manuscript

Lines 136-139

Specifically, the study will (1) evaluate the overall quantification accuracy of closed-path EC, AFG, bLs model, and the GPIM method in quantifying single-release single-point and multi-release single-point emissions that simulate oil and gas emissions, (2) determine the mean relative factor (estimated emissions over actual emission) for these models.

(1) Eddy covariance and aerodynamic flux gradient footprint calculation

Lines 254-265

Eddy covariance and AFG footprints were calculated using the Kljun et al. (2015) footprint model. Even though Rey-Sanchez et al. (2022) reported the Kljun et al. (2015) footprint model to be less accurate compared to the Kormann and Meixner (2001), Kormann and Meixner (2001) was too complex for our study because it required multiple sonic anemometers or tracer release experiments to calculate the exponential wind velocity power law, and the exponential eddy diffusivity power law for site specific data. Our study was limited to a single sonic anemometer, and this provided enough inputs for the Kljun et al. (2015) footprint model. The default pixel size 2 * 2 m was used in this study. This study first calculated the area that contributed 90% of the vertical flux; and based on the location of the point source, the source was determined if it was within the 90% footprint area. Point source emissions of sources within this region were then calculated based on the approach by Dumortier et al. (2019). This approach assumes all measured flux is equal to flux resulting from a single point source. In case of the mast being downwind of more than one source, more sonic anemometers are needed to solve the two unknown point source fluxes.

(2) Backward Lagrangian stochastic model

Lines 288-293

Pre-processed data from the GPIM method was used for bLs quantification. Quantification was done using the open-source software WindTrax 2.0 (Crenna, 2006; WindTrax 2.0, n.d.). For every 5-, 10- and 15-minute duration in the ±5º, ±10º, and ±20º, respectively, inputs included roughness length (z0), Monin-Obukhov length (*L*), mean (wind speed, wind direction, concentration, pressure, temperature), background concentration, source height, and distance from the emission point to sensor. WindTrax is also designed to quantify a single point source at a time, and hence, was only used to quantify single-point single emissions and multi-point single emissions.

Comment 2

As part of this study, critical choices are made related to the physics embedded in the covariance w'c' (equation 5) under different scenarios that an eddy covariance (EC) tower provides. More in-depth explanations of those choices will be helpful.

Authors Response

We have accordingly reanalyzed our data using EddyPro software and clearly stated our system configuration and pre-processing of the data using our non-standard eddy covariance system.

Changes to manuscript:

Section 2.4.1

2.4.1 Eddy Covariance

2.4.1.1 Data pre-processing

Evaluating the MGGA CH_4 data showed that actual sampling was between 4 and 12 Hz (highest sampling at 6 Hz), even though it had been set to sample at 10 Hz (Supplementary Information Section 2b). To account for this sampling variability, data were filtered to when sampling was equal/greater than 8 Hz. Data where the frequency was greater than 8 Hz were down sampled to 8 Hz. The sonic anemometer meteorological data (horizontal wind vectors (u, v), vertical wind vector (w), temperature (T), and pressure (P)) actual sampling varied between 7 and 9 Hz with the most frequent frequency at 8 Hz (Supplementary Information Section 2b). As the MGGA gas analyzer and sonic anemometer were not designed to clock synchronously, using the MGGA CH_4 clock time as a reference, meteorological data from the sonic anemometer were matched to the MGGA CH_4 data using linear interpolation to generate concentration-meteorological 8 Hz data.

The aggregated concentration-meteorological data were then merged with METEC's release data and metadata, and release event tables created. Release event tables were aggregated tables of concentration, meteorology and release (emission source location, duration and rate) information for all defined release events at METEC. The concentration-meteorological -release event data were then separated into single-release and multi-release events.

Single-release events were when there was a single emission point at the site level, while multi-release events were when there was more than one emission point at the site level. The concentration-meteorological-release event tables were split into 5, 10 and 15-minute release event tables (i.e. there was a continuous release in the duration). Based on the bearing of the emission point to the measurement point and the average wind direction in the duration, the data was further filtered to downwind data, ±5º, ±10º, ±20º, and ±45º.

2.4.1.2 Flux calculation

Turbulent fluxes were calculated using the open software EddyPro® version 7 (LI-COR, Nebraska, USA, n.d.). Acquisition frequency was set at 8 Hz, while file duration and the flux interval were set at 5, 10, and 15 minutes, respectively, depending on the file being processed. Table 1 shows the instruments input to the software.

Table 1. Anemometer and Gas Analyzer Input into EddyPro

Anemometer Information		**Gas Analyzer Information**	
Manufacturer	Young	Manufacturer	Other
Model	81000	Model	Generic closed path
Height	3 m	Tube length	300 cm
Wind data format	u, v, w	Tube inner diameter	3.275 mm
North alignment		Nominal tube flow rate	3.2 l/m
North off-set	0.0	Northward separation	0.00 cm
Northward separation	Reference	Eastward separation	0.00 cm
Eastward separation	Reference	Vertical separation	-10.00 cm
Vertical separation	Reference	Longitudinal path length	10.00 cm
Longitudinal path length		Transversal path length	2.54 cm
Transversal path length		Time response	0.4 s

In raw data processing, axis rotations for tilt correction under wind speed measurement offsets was checked. Under turbulent fluctuations, double rotation and block average detrend methods were used. Covariance maximization with default was used for time lag detection; time lags detection was checked. Compensation for density fluctuations (Webb-Pearman-Leuning terms) was unchecked as the MGGA analyzer synchronously reported dry CH_4 and water mole fractions, cell temperature and pressure. Mauder and Foken (2004) (0-1-2 system) were used for quality check. All statistical tests for raw data screening, Vickers and Mahrt (1997)– spike count/removal, amplitude resolution, drop-outs, absolute limits, skewness and kurtosis, discontinuities, time lags, angle of attack and steadiness of horizontal wind were checked. The default values for all these tests were used. Similarly, default settings for spectral analysis and corrections were used. Analytic correction of high-pass filtering effects (Moncrieff et al., 2005) for low frequency range; and correction of low-pass filtering effects (Fratini et al., 2012 - In situ analytic) and instruments separation (Horst and Lenschow, 2009 - only crosswind and vertical) in the high frequency range were used.

2.4.1.3 Post-processing

During post-processing, flux data were filtered based on (1) quality flags, Mauder and Foken (2004) (0-1-2 system), and (2) surface friction velocity ($u^* > 0.13$ m/s). Data that were flagged "2" were first filtered out as they were considered poor quality fluxes (LICOR, 2025), and the remaining dataset were filtered for high turbulence data. All data was filtered out as low quality and no further post-processing was done.

Comment 3

Equations 1-4 and their associated text can be moved to Supplemental Information, as they provide more introductory content. I also suggest moving the Gaussian Plume Model (equation 7) along with detailing the dispersion coefficients $\boldsymbol{\sigma}$ and other model parameters in the text to the SI.

Authors response

Thanks for your comment. All equations have been moved to Supplementary Information Section 2a.

Comment 4

While a detailed criticism of the assumptions embedded in the EC and other approaches is added in the discussion section by the authors, very little quantitative effort is made to confirm how several of these assumptions are being violated. For instance, when using the EC approach, no plots are provided, attempting to explain whether the local surface layer at the point of measurement is well mixed or not.

Authors response

Thank you for your comment. We have reanalyzed our data by accounting for these assumptions. For eddy covariance, EddyPro was used to account for factors such as time lags, stationarity and steady tests, and statistical tests that determined whether the data was usable for eddy covariance. Changes to manuscript are in comment 2 above. For the aerodynamic flux gradient, backward Lagrangian and the Gaussian plume inverse models, raw data are used by the assumption that by accounting for the distance, atmospheric stability, wind speed and height which are inputs to the model, we can estimate what the model quantifies in continuous measurements. The variability such as whether the plume is well mixed at the point of measurement is captured in the uncertainty. The point of the study is to check what uncertainties are associated with using continuous monitoring data as inputs for fence-line quantification as inputs to a model.

Comment 5

The decision to use an averaging time window of 30 minutes remains suspect as there are many METEC experiments with durations shorter than half an hour. Reynolds averaging is a critical piece behind the use of eddy covariance concepts and a choice of 30 mins based on discussion from a prior article on agricultural emissions isn't well justified.

Authors response

Thank you for your comment. We have reanalyzed our data to uniform 5 minutes, 10 minutes and 15-minute durations for all models where there were continuous durations. Even though there were short releases such as 10 s that represent intermittent emissions in oil and gas such as a venting of a gas pneumatic, our duration tables represent minute durations when there were continuous releases for that period. For example, a 5-minute event table is for a continuous release in a 5-minute duration. To clarify this, the following changes have been made to the manuscript.

Changes to Manuscript

Section 2.4.1.1

Lines 211-213: The concentration-meteorological-release event tables were split into 5, 10 and 15-minute release event tables (i.e. there was a continuous release in the duration).

Comment 6

I recommend providing a reference dataset of the raw measurements along with a comprehensive validation exercise. This helps readers in the evaluation of the accuracy of the data reduction procedures and to appreciate the inverse modeling choices.

Authors response

Thank you for comment. A comprehensive dataset used to evaluate the models has been uploaded.

URL: http://datadryad.org/stash/share/7s42bajRb2czaY9hr6NbTKDAolCWZ_pNrty0o54qXBE

Comment 7

I recommend a better flow of text and linkage between sections 4.1 and 4.2 (where authors refer to results) and section 3 to draw their conclusions.

Authors response

Thank you for your comment. The discussion section has been rewritten to reflect our results.

Changes to Manuscript

4 Discussion

Methane emissions quantification from oil and gas is a complex system comprising of gas emissions from different heights, different locations, encountering aerodynamic obstacles of different sizes, and of varying emissions duration, amongst others. The ability to precisely quantify emissions using data collected by a point sensor, downwind of a source is directly influenced by plume dynamics. The CH_4 plume downwind of a source will change in size and shape in different atmospheric conditions, in open areas versus areas with obstacles, diurnally, and in different seasons (Casal, 2008). In this study, the precision to which downwind methods (closed-path EC, AFG, GPIM and bLs) could quantify the emission rate of point source(s) were tested in different atmospheric conditions (rain, sunny, snow, windy, calm etc.), and aerodynamic scenarios (emissions sources in open areas, behind obstacles, changing atmospheric stability, and day/night). As a result, testing the predicted emission rates to controlled release rates in different conditions introduced real-world scenarios that have not previously been tested, hence better understanding model uncertainty in the application of quantifying emissions from oil and gas production infrastructure.

4.1 Eddy Covariance

Eddy covariance was tested using a closed-path analyzer, cavity ring-down spectroscopy, with a 3.2 lpm pump flowrate and a 0.4 s gas flow response time. The closed-path EC estimated emissions between a factor of 0.67 and 0.97 for SRSP emissions, and between 1.02 and 2.43 for MRSP emissions at ±45° wind sector range (Section 3.1). This was a wider uncertainty in estimated emissions than one reported by Dumortier et al. (2019), who estimated emissions at between 90 and 113% of true emission (~1.5 kg day^{-1}) with concentrations between 2 and 3 ppm. Our study tested closed-path EC at emission rates between 0.005 and 8.5 kg h^{-1}.

Our study's results were when the data was filtered for frequencies greater than 8 Hz, hence, largely reducing the sampled emissions. The 10 Hz sampling frequency set for this instrument was not a true 10 Hz and this could have been due to the 0.4 gas flow response time that delayed analysis of the drawn air sample in the cavity, or the 3 lpm pump flow rate for a 3 m tubing that might have varied the effective sample turnover rate. The rest of the data were flagged as low quality by Mauder and Foken (2004) (0-1-2 system), which flags based on steady state and well-developed turbulence. This could have been due to low turbulence as experiments were carried out in winter, and instrumentation limitations (low pump flow rate and asynchronous configuration of the gas analyzer and meteorological instrument).

Continuous monitoring requires deployment of multiple sensors which create limitations of cost and requires instrumentation with a wide measurement range as concentrations for oil and gas emissions can range between 0 to 250 ppm, as in this study (Supplementary Information Section 1). The currently available EC instruments have a narrow measurement range (LI-COR LI-7700 open path CH_4 analyzer has a measurement range of 0 to 25 ppm at -25 ºC and 0 to 40 ppm at 25ºC; PICARRO G2311-f, a closed-path analyzer has an operating range of 0 to 20 ppm). Also, the instrumentation should be environmentally robust and not lab-grade (be able to run smoothly in adverse weather conditions). Given these parameters, market available EC instruments that can currently be deployed in oil and gas are limited. The instrument used in this study is a field instrument (ABB MGGA GLA131 Series has a measurement range of 0 to 100 ppm for CH_4 but can be extended to 0 to 1%).

4.2 Aerodynamic Flux Gradient

Overall, the AFG method quantified emissions within an MRF of 1.3 to 1.7 for SRSP emissions and between an MRF of 2.4 and 3.3 for MRSP emissions (Section 3.2). The uncertainties in AFG were higher than EC especially for MRSP emissions but lower than the GPIM and bLs methods. The differences between AFG and EC could have been due to different instrumentation and analytical approaches that limited the exact comparison of the methods i.e. EC data was filtered for frequencies less than 8 Hz, and AFG instrumentations required both analyzers to be running, periods when one analyzer was down, were not tested. To our knowledge, this is the first study to test AFG for point source quantification and results are promising.

Compared to the EC method that requires a very fast analyzer which may be difficult to deploy in oil and gas, the AFG requires at least 2 analyzers sampling at 1 Hz frequency, which is currently possible with the range of sensors available in the market. The main advantage of flux gradient methods (EC and AFG) tested in this study is that they do not require background control as background CH_4 concentration is a highly variable parameter that cannot be controlled in open air especially when multiple emissions are happening. The AFG method relies on differences in CH_4 concentrations between two heights and this study shows that in complex sites where there are multiple sources, the method quantifies better than the point-source GPIM and bLs methods. The main limitation of the AFG and EC methods for point-source quantification is that when the measurement point is downwind of more than one source in a wind sector range, more than one sonic anemometers are required to estimate the flux of each source for footprint calculation based on Dumortier et al. (2019)'s calculations.

4.3 Gaussian Plume Inverse Method

The GPIM method quantified emissions within an MRF of 2.4 and 2.6 for SRSP and between 15.7 and 25 for MRSP emissions (Section 3.3). The GPIM method is a point-source specific quantification approach and works best in open areas, free of obstacles, and when the background concentration is well defined. For multiple emissions, in aerodynamically complex environments, even though the sensor is downwind of a single source based on average wind direction, quantification is complexed by interference from other neighboring sources. The GPIM has previously been reported to quantify emissions within 40.7 and 60% error for a single point-source, (Riddick et al., 2022b). However, GPIM correct quantification has been suggested to be better for longer distances where the plume is well mixed. This is typically a challenge for fence-line sensors that have to be deployed within the facility boundaries where large downwind distances may not be practical.

4.3 Backward Lagrangian Stochastic Model

The bLs method quantified emissions within an MRF of 0.8 to 1.05 for SRSP emissions and between 3.85 and 11958.8 MRF for MRSP emissions (Section 3.4). Similarly to the GPIM method, the bLs method used in this study is a point-source specific quantification method that simulates transport of molecules in open area and where the background concentration is defined. In this case, as with the SRSP test scenario, the bLs approach quantified within 20% uncertainty. However, for MRSP emissions, the bLs largely overestimated emissions and this could have been due to the interference of neighboring sources, that even though the measurement point is downwind of a single source, actual plumes are not distinct and model-simulated plumes may not be representative. The point-source bLs approach in WindTrax is also not designed for more than one downwind source.

Comment 8

In dispersion modeling efforts, the modeler connects raw measurements with their understanding of the complex boundary layer physics and then uses this to judiciously fix the free parameters of the chosen model while acknowledging the underlying limitations of the constitutive equations all along. Additional explanations are appreciated to provide details on how authors tackled this challenge.

Authors response

Thank you for your comment. This study investigates if the four established downwind models can be applied in oil and gas continuous monitoring i.e., can the model quantify an emission every time there is a detection for a 5, 10 or 15-minute duration. As such, we have fixed the parameters that are inputs to the model based on measurement conditions and our site in our revised manuscript. For example, for the Gaussian plume inverse model, we have reanalyzed our data such that the dispersion parameters are calculated based on sonic anemometer data, as opposed to literature values. This way, we have used site and atmospheric specific data for our calculations ensuring we have correctly used the model.

Comment 9

Line 390: "Oil and gas point sources violate assumptions (1), (2) and (4)". Assumption 2 requires the CH_4 fluxes to be turbulent. If they are not turbulent at the point of measurement, are they laminar? I'd recommend that the authors confirm this by plotting the power spectrum of the CH_4 concentration at the point of measurement and investigating the absence of the characteristic turbulence cascade in response. Our experience with continuous monitoring methane concentration data from METEC experiments referenced in the study unequivocally suggests that ambient concentration levels at measuring stations could be turbulent in nature.

Authors response

Thank you for your comment. After reprocessing our data using the EddyPro software, all data were flagged by quality check and friction velocity thresholding hence no further post-processing such as cospectra investigation was done. The Eddy covariance discussion was rewritten as below.

Changes to Manuscript

4.1 Eddy Covariance

Eddy covariance was tested using a closed-path analyzer, cavity ring-down spectroscopy, with a 3.2 lpm pump flowrate and a 0.4 s gas flow response time. The closed-path EC estimated emissions between a factor of 0.67 and 0.97 for SRSP emissions, and between 1.02 and 2.43 for MRSP emissions at ±45° wind sector range (Section 3.1). This was a wider uncertainty in estimated emissions than one reported by Dumortier et al. (2019), who estimated emissions at between 90 and 113% of true emission (~1.5 kg day^{-1}) with concentrations between 2 and 3 ppm. Our study tested closed-path EC at emission rates between 0.005 and 8.5 kg h^{-1}.

Our study's results were when the data was filtered for frequencies greater than 8 Hz, hence, largely reducing the sampled emissions. The 10 Hz sampling frequency set for this instrument was not a true 10 Hz and this could have been due to the 0.4 gas flow response time that delayed analysis of the drawn air sample in the cavity, or the 3 lpm pump flow rate for a 3 m tubing that might have varied the effective sample turnover rate. The rest of the data were flagged as low quality by Mauder and Foken (2004) (0-1-2 system), which flags based on steady state and well-developed turbulence. This could have been due to low turbulence as experiments were carried out in winter, and instrumentation limitations (low pump flow rate and asynchronous configuration of the gas analyzer and meteorological instrument).

Continuous monitoring requires deployment of multiple sensors which create limitations of cost and requires instrumentation with a wide measurement range as concentrations for oil and gas emissions can range between 0 to 250 ppm, as in this study (Supplementary Information Section 1). The currently available EC instruments have a narrow measurement range (LI-COR LI-7700 open path CH_4 analyzer has a measurement range of 0 to 25 ppm at -25 ºC and 0 to 40 ppm at 25ºC; PICARRO G2311-f, a closed-path analyzer has an operating range of 0 to 20 ppm). Also, the instrumentation should be environmentally robust and not lab-grade (be able to run smoothly in adverse weather conditions). Given these parameters, market available EC instruments that can currently be deployed in oil and gas are limited. The instrument used in this study is a field instrument (ABB MGGA GLA131 Series has a measurement range of 0 to 100 ppm for CH_4 but can be extended to 0 to 1%).

Comment 10

Assumption 4 states that measurements should be inside the boundary layer and in the constant stress layer. If the choice of RL from section 2.4.4 is to be taken at face value, then the constant stress layer extends up to 1m upward thus implying that measurements satisfy assumption 4.

Authors response

This statement has been withdrawn from our discussion as in the response to Comment 7 above. Also, we recalculated the roughness length from our sonic anemometer measurements in neutral conditions.

Changes to Manuscript

2.3 Calculation of Roughness Length

Surface roughness length (z0) was calculated from friction velocity (Supplementary Information Section 2a: Equations 1 and 2) by splitting the high frequency sonic anemometer data into 15-minute tables and filtering for those in neutral conditions, |L| > 500 (Supplementary Information Section 2a: Equation 3). The overall roughness length selected as the median of all the calculated z0 was 0.1 m (Rey-Sanchez et al., 2022).

Comment 11

Line 395-398: "Even though current eddy covariance application assumes the vertical flux at a point is independent of atmospheric stability (Denmead, 2008), atmospheric stability has an impact on point source gas …". While Denmaead (2008) notes that EC "is independent of atmospheric stability", it merely implies that EC by virtue of being a more fundamental approach relies on direct measurement of turbulent fluxes like <u'w'> and <u'θ'>, i.e. the information on atmospheric stability is implicitly built into the EC approaches. Apriori estimates of the Obhukov length scale that divide the surface layer into multiple regimes as required by the AFGM and Gaussian models are therefore not needed. The EC does not imply that the vertical flux is independent of atmospheric stability.

Authors response

Thank you for your comment. After reprocessing our data using the EddyPro software, all data were flagged by quality check and friction velocity thresholding hence no further post-processing. This statement has been withdrawn from our discussion as in the response to Comment 7 above.

Comment 12

Line 384-385 & 411: "Positive fluxes represent emissions and downward fluxes represent absorptions". This is not an assumption, but rather a statement of fact and an unnecessary one at that.

Authors response

This statement has been withdrawn from our discussion as in the response to Comment 7 above.

Comment 13

Line 391: "Emissions are collimated plumes instead of turbulent fluxes". It requires clarification as to what the authors mean when mentioning the phrase 'turbulent fluxes'. Collimated plumes are simply the smoothing effect of time averaging on an underlying turbulent structure. Please see the following references

- https://www.cambridge.org/highereducation/books/turbulent-flows/C58EFF59AF9B81AE6CFAC9ED16486B3A#overview
- https://epubs.siam.org/doi/pdf/10.1137/10080991X

Authors response

This statement has been withdrawn from our discussion as in the response to Comment 7 above.

Comment 14

Line 72: I wonder how are major shortcomings identified using fence-line approaches by Ilonze et al. (2024)?

Authors response

Ilonze et al. (2024) study compared continuous monitoring solutions and their reported quantification estimates based on what solutions reported. Details on specific factors that caused some solutions to overestimate are not provided. The study provides the overall performance of fence-line continuous monitoring sensors.

Comment 15

Line 219: "The roughness sublayer is set to 1" is not well justified. I suppose it means 1m? A roughness sublayer (RL) is a region immediately above the surface and below the inertial layer where horizontal in-homogeneity in flow variables persists. In other words, within the RL variables like <w'c'> (where c is the local methane concentration, w is the vertical wind speed, and ' represents the fluctuating field) can be assumed to be horizontally homogeneous. While there are well-established results in the literature on how to estimate the RL height, having access to direct point measurements at multiple heights offers a direct route to estimate the RL height. Please see the following reference.

- https://journals.aps.org/prfluids/abstract/10.1103/PhysRevFluids.3.114603

Authors response

We recalculated the roughness length from our sonic anemometer measurements in neutral conditions.

Changes to Manuscript

2.3 Calculation of Roughness Length

Surface roughness length (z0) was calculated from friction velocity (Supplementary Information Section 2a: Equations 1 and 2) by splitting the high frequency sonic anemometer data into 15-minute tables and filtering for those in neutral conditions, |L| > 500 (Supplementary Information Section 2a: Equation 3). The overall roughness length selected as the median of all the calculated z0 was 0.1 m (Rey-Sanchez et al., 2022).

Comment 16 and 17

Lines 430-431: "The main assumption of the Gaussian plume model is that CH4 emitted from a point source enters the airflow, disperses vertically and laterally, forming a conical plume (Riddick et al., 2022b; US EPA, 2013)". This is not an assumption but instead the standard response of the tracer being advected horizontally and vertically by the air.

Line 431-433: "The formation of a conical plume is hindered at oil and gas facilities by obstacles (equipment) and is affected by atmospheric stability." While strictly speaking sizable obstacles may hinder the plume, whether this is indeed the case for the METEC site is unclear. The manuscript does not offer proper evidence to support this argument. Given the sparsity of the few obstacles on the METEC site and the focus of the current study on distant, fenceline monitoring, it seems to reason that obstacles in fact do not hinder plume features.

Authors response

This statement has been withdrawn from our Gaussian plume discussion has been corrected as below.

Changes to manuscript

4.3 Gaussian Plume Inverse Method

The GPIM method quantified emissions within an MRF of 2.4 and 2.6 for SRSP and between 15.7 and 25 for MRSP emissions (Section 3.3). The GPIM method is a point-source specific quantification approach and works best in open areas, free of obstacles, and when the background concentration is well defined. For multiple emissions, in aerodynamically complex environments, even though the sensor is downwind of a single source based on average wind direction, quantification is complexed by interference from other neighboring sources. The GPIM has previously been reported to quantify emissions within 40.7 and 60% error for a single point-source, (Riddick et al., 2022b). However, GPIM correct quantification has been suggested to be better for longer distances where the plume is well mixed. This is typically a challenge for fence-line sensors that have to be deployed within the facility boundaries where large downwind distances may not be practical.

Comment 18

Line 463-465: "Even though these modeling approaches have been reported to work elsewhere (e.g., agricultural and landfill emissions), it does not necessarily mean it could work in the intended area of application." This blanket statement is unwarranted. Compared to many complex scenarios observed in agricultural and landfill emission cases, the current controlled-release tests present a much-simplified dataset both in terms of emission characteristics (discrete constant emissions rates from only 5 equipment groups all starting and stopping simultaneously) and site features (flat terrain with few sparsely spaced obstacles).

Authors response

This statement has been withdrawn and the implications section has been corrected as below.

Changes to manuscript

Lines 522-535

Oil and gas point sources could either be single emissions or multiple emissions occurring concurrently. In cases of multiple emissions with more than one release point being upwind, the Gaussian model and the backward Lagrangian stochastic models are limited, as they can only quantify one source at a time; and interference from neighboring emissions affects the underlying principles of dispersion on which these models were developed. As a result, flux quantification models used in other applications such as eddy covariance and aerodynamic flux gradient have been proposed as the solution. This study's results show that generally reasonable quantification estimates are achieved with flux approaches (eddy covariance and aerodynamic flux gradient), but these methods require more instrumentation effort (fast sampling analyzer for eddy covariance, and multiple collocated sensors for aerodynamic flux gradient). Even though the widely applied Gaussian plume inverse method and the backward Lagrangian stochastic models are widely used for single-point emissions, this study shows aerodynamic complexities, the difficulty in defining the background, and interference from neighboring sources challenge the application of these models for fence-line continuous monitoring. This study recommends more testing of flux quantification models for oil and gas quantification as they could improve emissions quantification for leak repair prioritization and methane reporting.