Dear editor,

This is a review of the paper submitted by Van Ettinger, van Heuven and Chen, describing the new implementation of a methane sensor by Axetris on a UAV platform.

General comments

The paper discusses initial validation tests with the cost-effective medium-precision Axetris sensor compared to a high-precision established sensor. Lab tests by Van Ettinger et al highlighted the importance of temperature control to reduce sensor noise. The Axetris sensor was then deployed on a drone to measure the methane emission rate from a dairy farm; the testing was conducted in parallel with the established AirCore method and the results show potential of the Axetris sensor for use in the mass balance approach. The authors conduct a detailed sensitivity analysis, which highlights the main factors of error in the method.

I think the work is relevant for many researchers and environmental scientists in the field of methane emission measurement. The novelty of the paper lies in the insight that a cost-effective medium-precision sensor is capable of providing accurate results on methane emission quantification. The uncertainty analysis is more extensive than what is usually found in the literature and that's very helpful. The paper is very well written in general, although I think that some more deeper discussion can be provided on a few specific topics (listed below). I also find that a few graphs are unclear at the moment; a better description may be needed there. Overall, I would like to recommend the following minor revisions before publication in AMT.

Specific comments

The title is very generic at the moment, and does not capture some of the main points of the paper. From a practical perspective, I think the key point is that the new Axetris sensor is cost-effective but still can provide promising results; I would therefore add something along these lines of "a cost-effective in situ methane sensor". Furthermore, on the title, I think "point source emissions" is too limiting: first of all, the Mass Balance Approach also applies to diffuse sources within a certain domain. And second, one could argue that a dairy farm used in the experiment produces more diffuse emissions (less of a point source, indeed) than, say, a vent stack in an oil & gas facility. I would therefore recommend to replace "quantify point source emissions" to something like "quantify emissions at facility level" or just "quantify emissions".

Drone-based methane sensing is a rapidly developing field, and I see that many references to existing measurement campaigns are from several years ago. For some latest references, I would recommend to read and refer to, e.g., the following recent papers and references therein:

- AMT - Controlled release testing of commercially available methane emission measurement technologies at the TADI facility (Audrey McManemin, Catherine Juéry, Vincent Blandin, James L. France, Philippine Burdeau, and Adam R. Brandt, 2026)
- Validation and demonstration of a drone-based method for quantifying fugitive methane emissions - ScienceDirect
  (C. Scheutz, J.E. Knudsen, N.T. Vechi, J. Knudsen, 2025)

I will come back to these references below, because some of the conclusions in these papers are in line with what Van Ettinger et al reported so it will be good to make that connection.

If the key novelty in van Ettinger et al's paper, over other established methods using expensive high-precision sensors used in the references above, is in the Axetris sensor that is low-cost but requires temperature control, then a few considerations need to be discussed in further depth. First, it is unclear now in how far Axetris themselves have already done lab testing before bringing the sensor on the market. What has already been tested, and how does the lab testing by the Ettinger et al build on that? Second, for anyone wanting to deploy the sensor on a drone themselves, it will be important to know how the temperature control is implemented. What is required? Is this available on the market or do people have to develop it themselves? What is the complexity of this solution, i.e. how much would it cost approximately?

Another issue is the wind measurement implementation. I understand from Van Ettinger et al that they did measure the wind at the location of the UAV, but in the end the data was not used for the mass balance calculations. Some discussion is warranted about the implementation that Van Ettinger et al tested. Why did it not give useful results? Is this something that can be improved in future? Let me say that it is not easy to measure wind at the location of the UAV accurately, but e.g. Scheutz et al (2025) do manage it and show the value of the data in the methane emission quantification analyses. Some discussion is needed about how important this may be and what can be done in the future to improve wind measurements at the drone.

In the field trial, the Axetris sensor is compared to the AirCore method. I understand that this may have been a practical choice due to availability of the equipment, but it does raise the problem that there are two distinct differences have to be evaluated: the difference in performance between the sensors, and the potential difference induced by the use of the data analytics required on the AirCore data (sampling, mapping of concentration data onto the original UAV trajectory, etcetera). In an ideal scenario, I think it would have been preferable to compare the Axetris sensor to another (expensive but established) in situ sensor that gives high-precision and high-frequency data, mounted on the same UAV: then the readings for the concentration measurements can be directly compared to each other, and this will probably lead to further insights on the performance of the Axetris sensor. Of course I am not suggesting that such an experiment should be included in the current paper, but I think it does deserve to be mentioned as a suggestion for future work.

Based on the observations above, I feel that some conclusions are a bit overstated, in particular “The close agreement between the techniques validates the use of the Axetris sensor for robust flux quantification” (line 769). I think it is premature to use words like “validates” and “robust” for a method that has been tested on only five flights downwind (of which four flights were successful) of a dairy farm, from which the mass emission rate was not known at source level. I agree with the authors that the Axetris implementation has potential and that the results are worth reporting on in a scientific paper, but further testing will be required in different wind conditions and at different facilities before a robust validation can be claimed. In this light, I think further test campaigns, especially with controlled releases of methane, can be suggested as next steps in the Discussion or the Conclusions, to further evaluate the Axetris implementation – in addition to the side-by-side testing with a high-precision sensor as suggested above.

Technical questions/issues/suggestions

- Line 66: examples are from 2016 and 2021. Please consider adding more recent papers on UAV deployments. E.g. the two papers mentioned above and references therein.
- Line 74: I know that some papers in the literature do use the word “flux” as a synonym for “mass emission rate” but from a fluid dynamics perspective the concepts are distinct. A flux is a mass emission rate per unit of area (e.g. in $g/(m^2 s)$, for a diffuse emission from a large area like a landfill or biological processes). Here and henceforth, I would therefore recommend to use “mass emission rate” for the quantity that has actually been measured from the farm – not “flux”.
- Line 131: what does “ground time” mean?
- Line 175 (equation): the equation does not go through (0,0). Is this a problem, for instance when extrapolating these results to higher or lower concentrations than observed in the field trial?
- A related question on the Figure B1 (page 30): why do the outlier points in Figure B1 seem to lie on a hyperbolic tangent-like curve rather than on random distribution around the straight fitting line? Perhaps it’s my limited understanding, but I don’t think there’s an explanation in lines 167-181 for this hyperbolic tangent-like data.
- Line 187: as I mentioned under the “Specific comments”, I am curious to know if Axetris hasn’t performed any such measurement themselves on their sensor before bringing it to market. If they did do these tests, what were the results?

- Lines 301: “for direct comparison of our results with theirs”. It should be added that there is no evidence that the methane emission rate from the site was the same though. In fact, this point is made later in the paper, but it would be appropriate to mention it here already as well. This is not a controlled release test where the emissions are controlled and known to be the same as what Vinkovic measured.
- Line 326 and below: “This logarithmic wind profile is used for calculation of fluxes”. As mentioned under “Specific comments”, some discussion may be needed about the causes of the noise in the TriSonica wind measurements that made that these in situ measurements could not be used in the mass balance approach (compare for instance with the discussion in Scheutz et al (2025)).
- Line 385: Equation uses x and y for coordinates in vertical plane; z is used for the observed value in equation 3. On the next page (Equation 4), the parameter z is used for the vertical coordinate. This needs to be made consistent.
- Line 405, equation 4: The original mass balance method has cos(theta) inside the summation, because the method allows for changing wind directions to be included (see e.g. Mohammadloo (2025) for a derivation, which shows the dot product with the wind velocity and the vertical curtain’s orientation). Taking cos(theta) outside of the summation is an additional assumption that needs to be noted down.
- Line 430 “on visual inspection”: this approach looks subjective, and a possible cause for further uncertainty in the results. I didn’t see a clear discussion in Chapter 4 on this: can the visual inspection approach lead to errors or uncertainties not already accounted for in the sensitivity analysis?
- Line 475: “Performing multiple passes across different altitudes, these plume-displacements can be captured and accounted for in the final flux estimate.” This observation is in line with Scheutz et al (2025), see e.g. their Fig 7; a reference can be made to that paper.
- Figure 3 top plot: How was the LOWESS smoothing done? In Figure 3’s top plot, it seems that the original Axetris data has much higher peaks than the smoothed data, but the troughs are similar. Was the LOWESS smoothing really mass-conserving? Perhaps an equation can be provided to show this.
- Figure 3 caption: ”The middle of the barn is at 0m horizontal distance”. Many people will intuitively understand what is meant here, but the wording a bit sloppy and can be improved. The barn is not actually located in the plane flown by the drone, of which we are seeing the integrated contour plots. It may also be nice to mention the drone’s downwind distance to the farm here.
- Line 577: “Increasing the flight duration lowers the CI bounds and the standard deviation” . This finding seems to be again in line with Scheutz et al (2025).
- Lines 627-632: The current explanation for the difference with the observations by Mohammadloo et al is not clear. In particular, does “changing atmospheric

conditions” relate to a spatial difference between the ground-based anemometer and the wind speed at the location of the drone? Otherwise, could it perhaps be related to how Ettinger et al have used a mean wind direction in the MBA rather than the actual time-varying wind direction (see my earlier comment on line 405)?

- Line 747-751: I completely agree with this paragraph, but the authors could perhaps add that the effectiveness of their current solution can also be improved in future by simply removing the heavy Aircore equipment from the drone. This will enhance the flight endurance of the system and would allow for more repeated measurements.
- Line 756: “We improved the sensor's performance by properly insulating the sensor and applying active thermal regulation to maintain a constant cell temperature”. As noted under the Specific comments, some discussion is needed on how difficult/costly it is to implement such an enhancement for temperature control.
- Line 1003: this is presumably flight 2, not 1.