Reviewer 1

General comments

This manuscript presents comprehensive analysis of the use of different UAV systems and calculation methods to quantify methane points emissions in an Arctic seep area. The two UAV systems were equipped with open-path and close-path methane instruments, along with two different onboard 2D anemometers. This study further compares methane emissions calculated using mass balance approach and Gaussian plume inversion, finding that the mass balance approach provides more robust quantification with smaller uncertainties.

Overall, this manuscript is suitable for AMT. My main concerns relate to how wind measurements were compared between onboard and ground-based anemometers. Since different wind measurements were used to calculate emissions, it is unclear how the results can be directly compared when different anemometers were applied. Please refer to the specific comments below. I would recommend publication after consideration of the following comments.

We would like to thank the reviewer for the constructive feedback and insightful comments. Our detailed responses to the reviewer's comments are provided below in blue color and statements added or revised in the manuscript are provided in italics. Regarding wind measurements, for all emission calculations, we used onboard wind measurements. The ground-based sensors were only used to check and confirm the on-board measurements and to align the curtain with orthogonal wind direction during flight planning. Please see our response to comment # 1.

Specific comments:

1. Line 100-110, The two UAV setups used different 2D anemometers. The onboard instruments measure relative wind speed measurements (apparent wind). Was true airspeed measured on the UAVs? What is the impact of using different 2D anemometers on the emission calculations? How were wind measurements compared between onboard and ground-based measurements? (Line 110). Please clarify.

   Thank you for the comment. Indeed, we used two different 2D anemometers on board the UAVs. For both UAVs, the true airspeed was measured using a GPS sensor, which was then used to correct the relative wind speed measured by the on board anemometers. Although the make and model of the anemometers are different, they should, under ideal conditions, both measure the same wind speed and direction within their uncertainty limits in a side-by-side comparison. However, the reviewer is correct that the measurements of two different systems may not always be comparable, which sometimes is the case under different field conditions. As the reviewer suggested, we compared the wind measurements recorded by all of the sensors (two ground-based and two on-board), during the flights and added these as an Appendix in the revised manuscript. As can be seen from these figures, the wind direction is consistent among all sensors. When comparing the wind speeds, it should be noted that the anemometers are each measuring at different altitudes. Also note the spatial difference between CP-1 and OP-2 and vice versa in wind speed measurements. Overall, while the two UAVs utilized different anemometer models, our analysis in Appendix D demonstrates that the measurements are consistent within the combined uncertainty ranges of the sensors. The observed variations in wind speed are attributed to the spatial gradients between the two curtain locations (150 m vs 80 m downwind) and the increase in wind speed with altitude, rather than sensor bias. Per reviewer request, we added this comparison in Appendix D in the revised manuscript as follows.

   The anemometer deployed on UAV-MPI, 0.67 m above the rotor plane, recorded wind measurements at 2 Hz with a reported accuracy of $\pm 0.2\ \mathrm{m\,s^{-1}}$ *for speed and* ± 1.0 *°for direction. UAV-NRCan is a DJI Matrice 300 RTK quad-copter equipped with a* $\mathrm{CH_4}$ *gas analyzer custom-built by the National Research Council of Canada (NRC), and a 2D anemometer (WindUltra, Gill Instruments) placed 0.75 m above the rotor plane to measure wind speed and direction.*

   The wind speed measurements are relatively consistent between the UAV platforms, and the wind conditions are similar for the far- and near-curtain flights. More details can be found in Appendix D, where the measurements of ground-based sensors were also included.

Measured wind speeds from all four curtain flights are illustrated as a function of altitude in Fig. 3 (see also Appendix D).

Appendix D: Wind speed and direction comparison

Figure D1 shows the measured wind direction and speed during all curtain flights and from ground-based sensors. Note that UAV-based wind measurements depart from the ground-based measurements as UAVs ascend during the curtain flight. The differences between the on-board wind measurements (CP-1 and OP-2, CP-2 and OP-1) are primarily due to spatial differences of the curtains (i.e. 150 vs 80 m downwind distance from seep location) and different flight altitudes. This further demonstrates that all wind speed measurements are consistent throughout the measurement duration. We placed the ground-based sensors close to the seep location at two different heights, one at about 1.5 m (Windsonic4) above ground level and other (Gill Windultra) at about 2.7 m, while UAV-based anemometers were placed 0.67 and 0.75 m above the rotor plane in UAV-MPI and UAV-NRCan, respectively. Wind direction measurements agree well with the ground-based sensor after correcting the measurements from UAV-MPI and ground sensor (Windsonic4) north alignment.

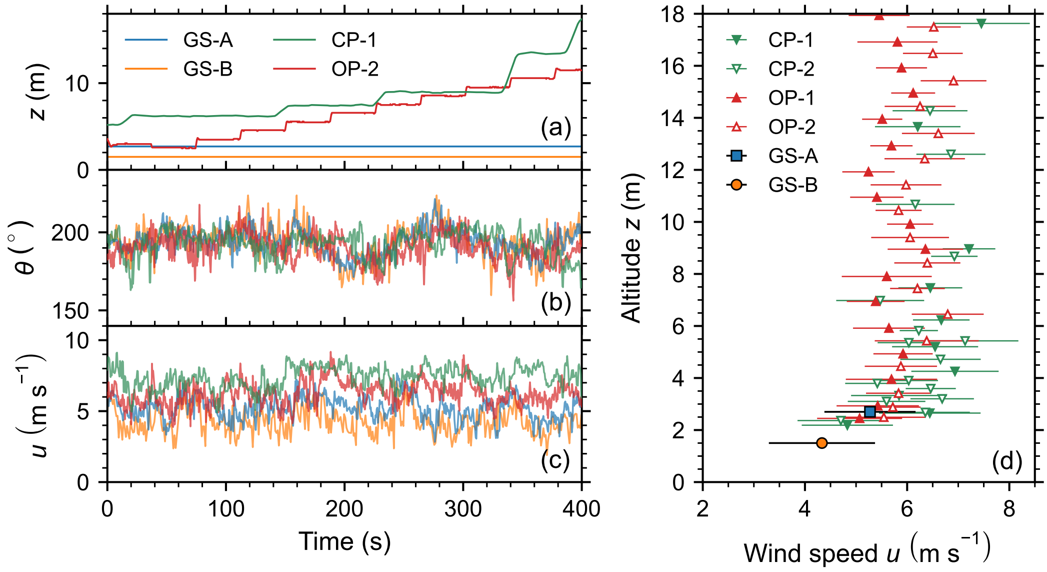

Figure 1. Comparison of wind measurements during CP-1 and OP-2 flights: (a) the altitudes of ground sensors and both UAVs, (b) wind direction measurements, and (c) wind speed measurements from both UAV platforms and ground sensors (GS-1: WindSonic4; GS-2: Gill WindUltra). (d) Wind speed measurements from all platforms during all four flights at different altitudes, where each symbol represents the mean wind speed and horizontal bars represent the standard deviations.

2. Line 218, how was the background concentration determined? Could the background level vary with altitude? The background concentration appears to differ between UAV-MPI and UAV-NRCan. How large is the uncertainty associated with background concentration when calculating emissions using different methods?

Thanks for the reviewer comment. The background mixing ratio was derived from the average of sampling points outside of the plume-affected regions, determined independently for each of the gas analyzers. The background concentration can vary with altitude, which can cause biases in our emission rate estimation, nevertheless we do not anticipate significant background variation from the altitudes covered in this study. To account for this, we now added the background uncertainty in our uncertainty budget estimation. To be conservative, we have defined this error based on the $\pm 1\sigma$ of the points we used to estimate the background concentration and propagated this to our flux calculations as was practiced in Yong et al. (2024). This additional uncertainty accounts for 3 % of CP flux calculations and between 10-13 % of OP flux calculations as $\pm 1\sigma$ was 3 ppb for CP and 9 ppb for OP analyzer. The difference between the background concentration after applying the water and temperature corrections to OP measurements became very small. The revised background methane dry mole fractions are 2031.8 and 2029.1 ppb for CP and OP, respectively We have revised the results, manuscript lines 155 - 158, 194 - 199, and Fig. 2 (Fig. B1 in revised manuscript) to indicate the background estimated points as follows.

A constant background $\mathrm{CH_4}$ *of 2031.8 ppb and 2029.1 ppb is removed from the measured dry mole fractions for UAV-MPI and UAV-NRCan, respectively, where these background values were estimated by averaging sampling points outside of the plume-affected regions (see Fig. B1).*

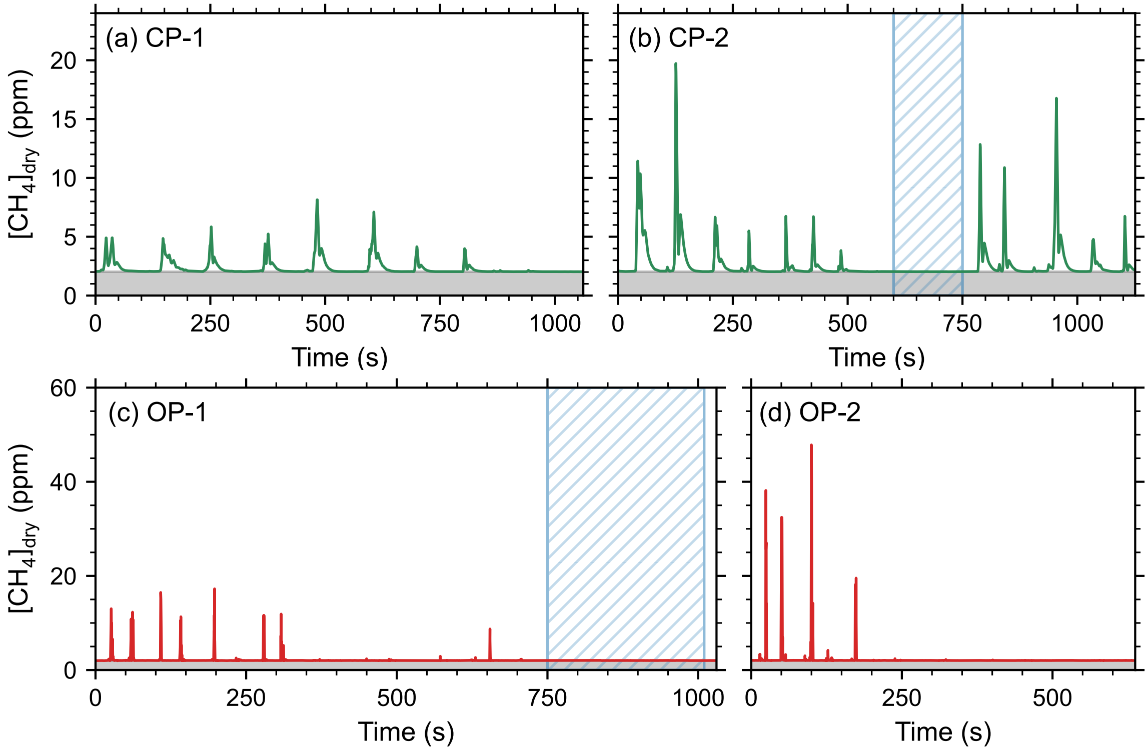

Figure 2. Measured methane concentration timeseries for the four curtain flights, labeled CP-1, CP-2, OP-1, and OP-2. The shaded regions indicate the background methane concentration, recorded as 2.0318 ppm for the closed-path sensor (a,b) and 2.0291 ppm for the open-path sensor (c,d). The background concentrations were estimated by averaging the measurements within the dashed region.

Using constant background concentration may cause bias in our flux estimations as background concentration may vary. To account for this in our uncertainty budget, we used $\pm 1\sigma$ *of the background concentration and propagated this as a systematic error source in our flux estimations (Yong et al. 2024). This yielded about 3 % additional uncertainty for CP flux estimates and between 10-13% for OP flux estimates as* $\pm 1\sigma$ *corresponds to about 3 ppb for CP and 9 ppb for OP analyzer. We note that this difference between the sensors originates from different noise characteristics of the sensors rather than being a physical difference in background.*

3. In addition to the temperature (Appendix A), how stable was the pressure during flight? How might pressure variations affect the measurements?

Thanks for the reviewer comment. The pressure during the flights was relatively stable, with a difference of 0.3 kPa over the range of flight altitudes. The closed path analyzer regulates the internal cell pressure at 240 millibars hence the variation in outside pressure should not have any impact on concentration measurements. The OP analyzer, on the other hand, could be influenced by pressure fluctuations; however, since these variations are minimal, their impact is expected to be negligible. We have verified that changes in the sensor baseline show no correlation with altitude (and the associated pressure changes) across the range relevant to this study.

4. Was the impact of water vapor on methane measurements considered? Were any drying systems or correction equations applied?

   Thanks for the reviewer comments. The CP measures $\mathrm{CH_4}$ dry mole fraction as well as the water mole fraction and dry mixing ratio was used to calculate the emissions. However the water vapor correction for OP analyzer was omitted in the original submission. We have now corrected the OP measurements to account for both the volumetric and spectroscopic effects of water vapor interference as well as for temperature, and repeated the emission rate calculations. When correcting for water vapor, we used the average water mole fraction from CP analyzer over the entire measurement period. The average water vapor mole fraction was 1.15% with a standard deviation of 0.02%.

   Additionally, we had overlooked the need to correct the flux plane for the water mole fraction when estimating the emission flux. We have now corrected this omission, thanks to the reviewers' comments. We have revised the manuscript lines 160 - 165 as follows and the respective figures.

$$\rho_{\mathrm{CH_4}}(z) = \frac{P(z)M_{\mathrm{CH_4}}}{R\,T_{\mathrm{avg}}}(100\% - \mathrm{H2O(y,z)}) \tag{1}$$

where $P(z)$ *is the altitude-dependent pressure,* $\mathrm{H2O(y,z)}$ *is the measured water vapor mole fraction in percentage,* $M_{\mathrm{CH_4}}$ *is the molar mass of* $\mathrm{CH_4}$ *(*$16.04\ \mathrm{g\,mol^{-1}}$*),* R *is the universal gas constant (*$8.314\ \mathrm{m^3PaK^{-1}mol^{-1}}$*), and* T_{avg} *is the average temperature.* $P(z)$ *is a regression function that was derived from pressure measurements of UAV-NRCan, and* T_{avg} *was calculated using the ground sensor measurement.*

Technical comments:

1. Line 147, please correct "whichis"

   Thanks for the reviewer comment, please see the corrected typo in the revised manuscript.

1 References

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