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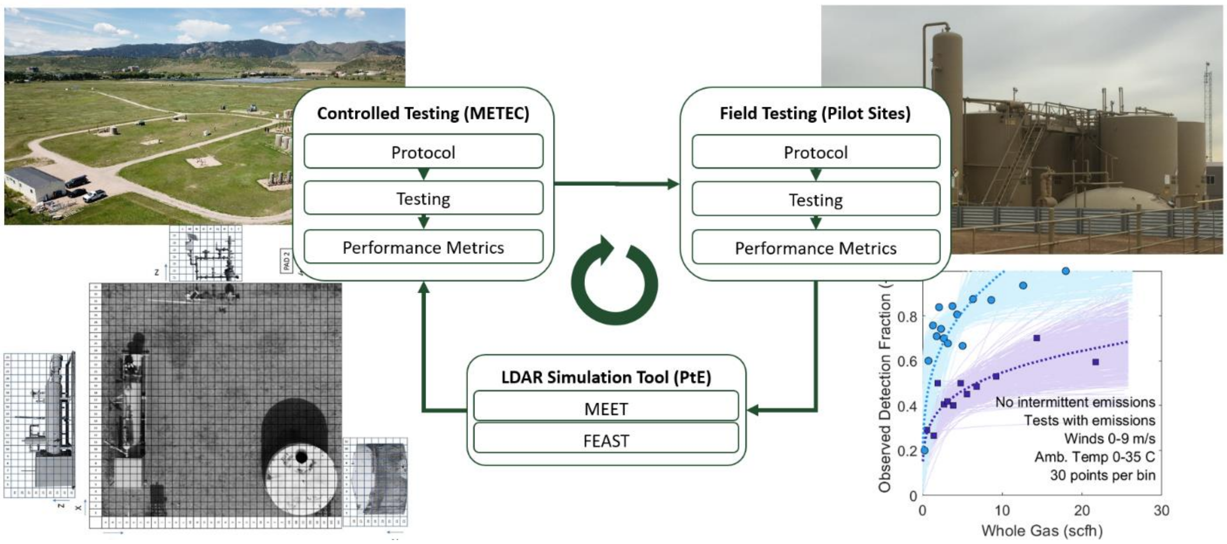

CURRENT PROJECT OVERVIEW

Methane is responsible for about 30% of climate forcing globally hence making methane emissions a serious concern. Partly in response to this challenge, multi-stakeholder efforts are driving the rapid development of new generation leak detection and/or quantification (LDAQ) solutions that promise improved emissions reduction than existing regulatory-approved detection methods. The United State Environment Protection Agency (USEPA) promulgated the implementation of structured and periodic leak detection and repair (LDAR) programs by oil and gas operators. LDAR is typically actualized using regulatory approved methods like USEPA method 21 or handheld optical gas imaging (OGI) surveys. For new generation LDAQ solutions to be regulatory approved for LDAR and other emissions-accounting programs, they must demonstrate equivalent or better control efficacy than existing traditional methods. The Advancing Development of Emissions Detection (ADED) program develops and implements comprehensive, standardized/consensus testing protocols with metrics to assess and compare the performance of solutions. The protocol development involved collaborations from oil and gas (O&G) operators, LDAQ solution developers, state/federal regulators, and environmental non-governmental organizations (NGOs) all of which formed the protocol development committee. The ADED project will (1) develop and implement controlled testing protocols for both continuous monitors and survey solutions at CSU's Methane Emissions Technology Evaluation Center (METEC); (2) develop and implement field testing protocols for both continuous monitors and survey solutions at a variety of oil and gas facilities; (3) Review and improve both the controlled testing and field trial protocols. My work has been focused on the implementation and improvement of the controlled testing protocol and the performance assessment metrics.

RESEARCH PROGRESS

Thus far, the ADED project has completed controlled release testing of at least 12 and 17 different survey solutions and continuous monitors respectively at METEC of which some of them have retested several times as of September 2023.

Essentially, 3 rounds of testing of continuous monitors have been completed thus far with peer-reviewed publications (1 published and 1 in preprint) completed for 2 of the 3 testing cycles.

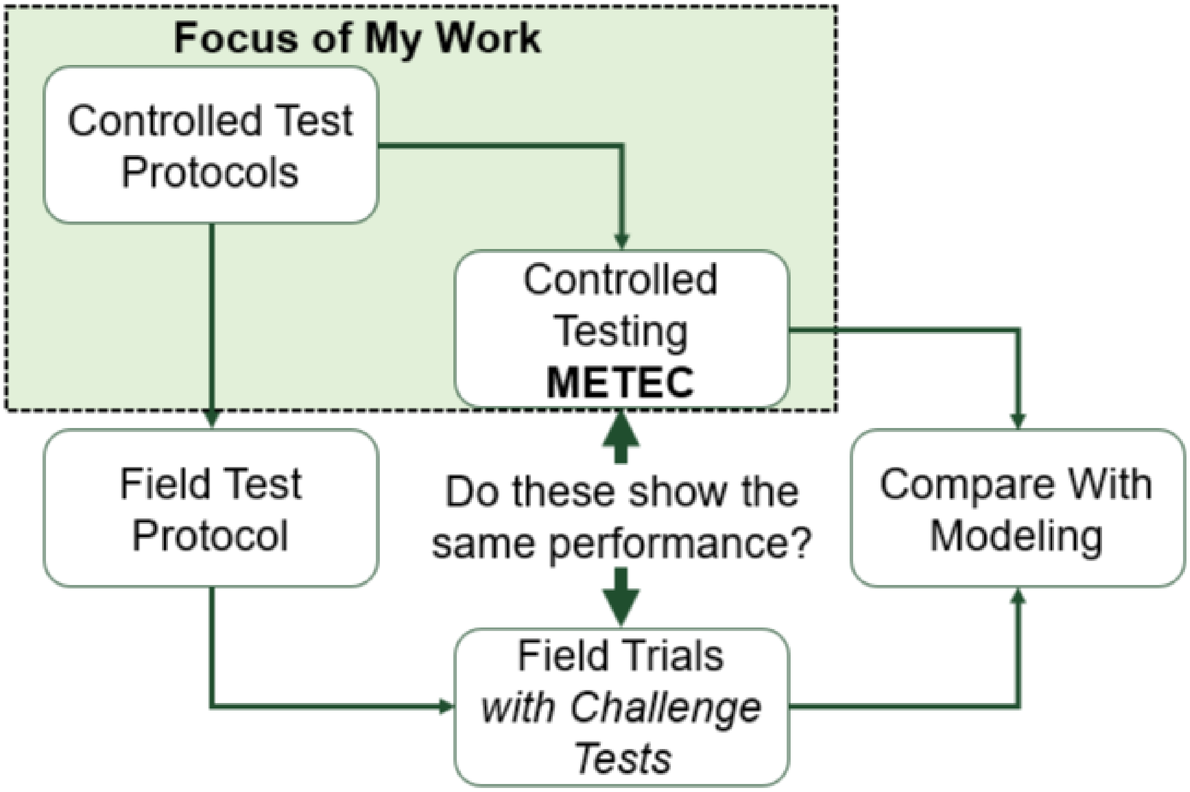

Figure 2: Workflow of the ADED project with my area of interest highlighted.

The protocol assessed and compared the performance of solutions based on metrics which includes probability of detection, quantification accuracy, emission source localization accuracy and precision, operational factor, and time to detection. Testing was single-blind (performers were unaware of the timing, number of emitters, rate of releases, and location of releases) and was conducted day and night across all permissible weather conditions for weeks (10+). For any continuous monitor, the protocol tested the combination of its sensors, mode of deployment, and analytics as an integrated unit, henceforth known as a method. Due to confidentiality agreement, participating solutions were identified with alphabets. Results from the first (2022/previous) and second (2023/current) round of the controlled testing of continuous emission monitors are summarized with results of the 4 solutions that retested in the second round used for illustration below:

- **Probability of Detection:** Results indicated that in contrast to the first round of testing, solutions showed more efforts at balancing low method detection limit (emission rate at which a solution has 90% chance of detection), low false negative rate (fraction of controlled releases that were not identified by a solution), and low false positive rate (Fraction of detection reports that could not be attributed to a controlled release) in the second round of testing than in the first round. For the 4 solutions that retested, their MDL, FN rate, and FP rate reduced (improved) relative to the first round.

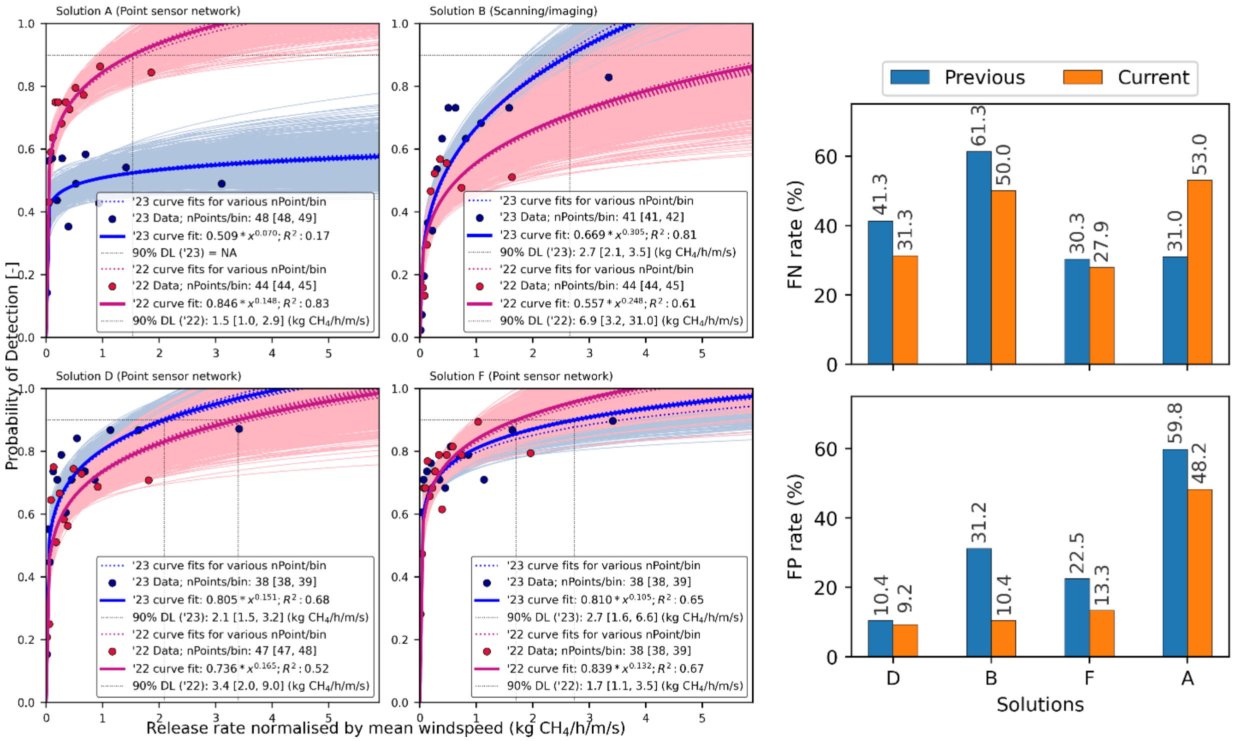

Figure 3: Probability of detection curves (left), FN rate (top right), and FP rate (bottom right) for the 4 solutions.

- **Quantification Accuracy:** For emission rate ranges [0.1 - 1) kg CH4/h and >1 kg CH4/h, 4 and 3 solutions had fraction of estimates within a factor of 3 greater than the highest values (76% and 80% respectively) obtained in the first round of testing. For controlled releases within the range [0.1 - 1) kg CH4/h, the percentage of estimates within a factor of 3 increased for solutions 3 of 4 solutions that retested while 2 of 4 solutions for emission rates in the range >1 kg CH4/h. Generally, although estimation accuracy or the tendency for under-estimation increased with release rate, the uncertainty on single estimates remains wide (under- and over-estimation by factors > 15 & 97).

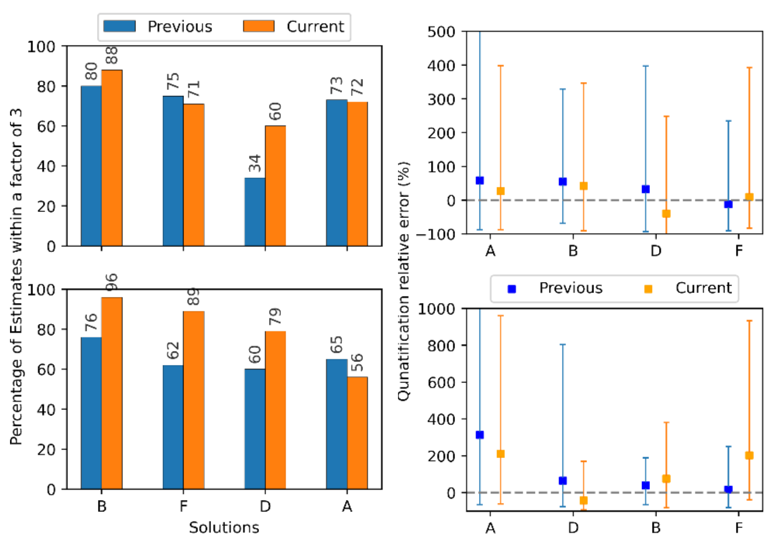

Figure 4: The top and bottom rows are for rates > 1 kg CH4/h and (0.1, 1] kg CH4/h respectively. The left figure represents the percentage of estimates within a factor of 3 while the right shows the mean error with 95% CI.

- **Emission Source Localization Accuracy and Precision:** Results indicate that 40% of solutions had localization precision > 50% against 27% of solutions in the first round of testing. Similarly, 50% of solutions had localization accuracy > 30% against 27% of solutions in the first round of testing. Additionally, results from the second round of testing showed that all scanning/imaging solutions had the best localization performance compared to point sensor network solutions.

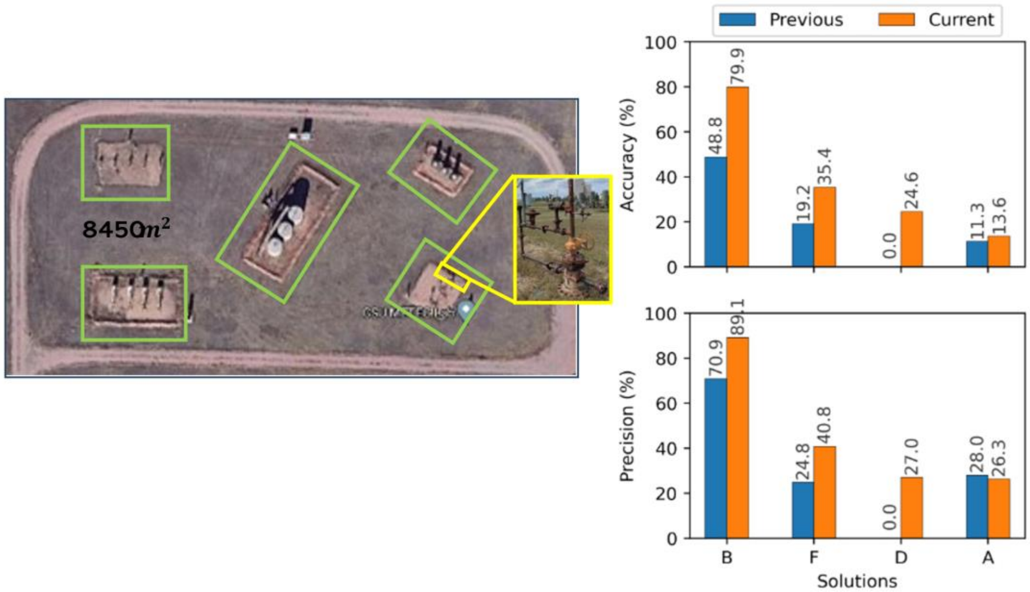

Figure 5: The figure on the left shows the equipment groups (clusters of similar adjacent equipment units). For the figure to the right, the lower figure shows the fraction of true positive detection localized at the equipment unit level (localization precision) while the upper figure shows the fraction of detection reports correctly atributing the emitter to an equipment unit level (localization accuracy).

- **Operational Factor and Time to Detection:** Results indicate that 50% of solutions had mean times to detection < 5 hours with upper CI limits < 15 hours compared to 27% solutions in the first round of testing. Similarly, 30% of solutions had upper limits less than the maximum release duration compared to 9% of solutions in the first round.

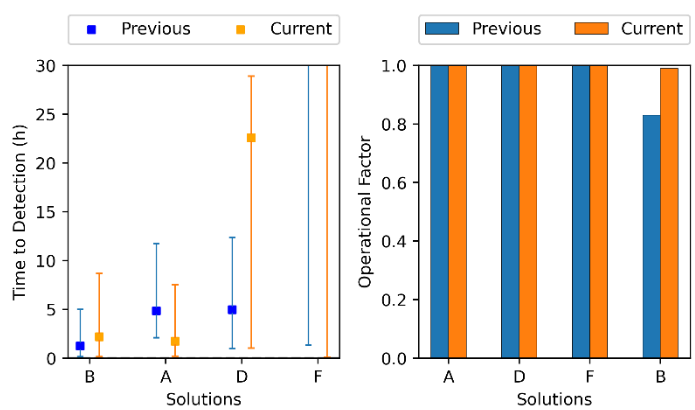

Figure 5: The figure on the left shows- and compares the time to detection for the 4 solutions that retested with 95% empirical CI on the mean showed as whiskers. The right side shows and compares the fraction of time that solutions were collecting and transmitting measurement data during testing periods (operational factors).

Additionally, 80% of solutions were operational ~90% of the deployment time compared to 72% of solutions in the first round. The United States Environmental Protection Agency advocates for operational downtime < 10% (operational factor > 90%) in their proposed amendment of the subpart W of the greenhouse gas reporting program for continuous emission monitors.

Given that the protocol (through the metrics) assessed inferences from the analytics of solutions, the improvements (or the lack of it) in performance observed in the second round of testing relative to the first indicates likely improvement (or the lack of it) of the analytics of some solutions. Additionally, relative to the first round of testing, higher rate and longer duration-controlled releases were conducted during the second round. This increases ambient gas concentration with solutions likely having multiple opportunities (for imaging solutions) or longer averaging time (point network sensor solutions) to take measurements. Also testing at calmer wind speeds likely reduced turbulent gas plume dispersion in support of more stable/steady measurements.

The results from the second round of testing highlighted the importance of regular, robust testing to the development of continuous monitors. Solutions that retested exhibited better performance on many metrics assessed relative to (1) their results in the first round of testing and (2) other solutions that tested in the second round.

RESEARCH PLANS

1. Analyze the controlled testing performance of survey solutions.
2. Re-evaluate the available controlled testing data of continuous monitors using new performance metrics.
3. Detailed analysis of the impact of meteorological and environmental data on performance of solutions using existing metrics.
4. Systematic analysis of the impact of the number and location of sensors on the performance of continuous monitors.

PUBLICATIONS

- Clay Bell, **Chiemezie Ilonze**, Aidan Duggan, Daniel Zimmerle (2023). "Performance of Continuous Emission Monitoring Solutions under a Single-Blind Controlled Testing Protocol". *ACS: Environmental Science & Technology.* 57, 5794-5805. DOI: https://pubs.acs.org/doi/10.1021/acs.est.2c09235.
- **Chiemezie Ilonze**, Emerson Ethan, Aidan Duggan, Daniel Zimmerle (2023). "Assessing the Progress of Continuous Emission Monitoring Solutions Under Single-Blind Controlled Testing Protocol". *ChemRxiv (Preprint).* https://chemrxiv.org/engage/chemrxiv/article-details/65298bd3bda59ceb9a869920.
- **Chiemezie Ilonze**, Jiayang (Lyra) Wang, Arvind Ravikumar, Clay Bell, Daniel Zimmerle (2023). "Methane Quantification Performance of the Quantitative Optical Gas Imaging (QOGI) System Using Single-Blind Controlled Release Assessment". *ACS: Environmental Science & Technology.* (**Ready for submission**)

Literature/Sources cited

https://energy.colostate.edu/metec/aded/