Rachel Day, MS Systems Engineering

Current Project Overview

An increase in awareness and concern of the human effect on global warming has prompted actions to reduce methane emissions, including in the oil and gas (O&G) sector here in the United States. Due to this demand, funding has been allocated from various stakeholders, increasing the emission detection capabilities, and prompting research into emission measurement solutions. Under Colorado State University's (CSU) Advancing Development of Emissions Detection (ADED) project, the Methane Emissions Technology Evaluation Center (METEC) was created to simulate natural gas emissions occurring at oil and gas field sites. Controlled testing of methane emission measurement solutions is conducted regularly at METEC and the focus has been directed towards developing comprehensive test protocols that can be used at METEC and operating oil and gas sites globally.

My research under the ADED program has included evaluating the performance of continuous monitoring point sensor networks (CMPS) at operating oil and gas facilities. These evaluations occur during deployments of field campaigns at O&G facilities in varying basins across the US. With the intermittent nature of high-volume methane emission events, CMPSs were created to monitor or measure emission sources and alert an operator for follow-up action. Little testing has been conducted on the performance of CMPSs under field conditions, so my work focuses on evaluating the detection limits and accuracy of emission estimates produced during the field campaign. Verifying the accuracy of the CMPSs detections, attributions, and quantifications assists in ADED's overall goal of increasing the adaptation of methane measurement solutions by O&G operators.

During field campaigns, our team works with operators to conduct controlled releases at facility locations where the solutions from multiple companies are installed. From the CMPSs' dashboards, I have been analyzing concentration measurements, wind speed and wind direction measurements, attribution estimates, and site level quantification estimates for each solution (if available). During each release, data were evaluated to identify if clear indications of the emissions were observed (detection), if the systems correctly identified the source location (attribution), and if emission rate estimates were accurate (quantification).

Research Progress

At this point in my research, I participated in a field campaign of controlled releases at O&G production sites and gathering stations in the Upper Green River, Marcellus, and Permian basins.

During the last field campaign from 2022 to 2023, 165 controlled releases of natural gas were conducted at varied locations on the sites, which were selected to simulate potential emission sources at the facility. During this field campaign 7 CMPS solution companies participated in controlled release testing. Raw data from each solution's dashboard was exported to analyze the probability of detection (POD), which was then compared to the POD results from the solutions that performed controlled release testing at METEC, as shown in Figure 1 below.

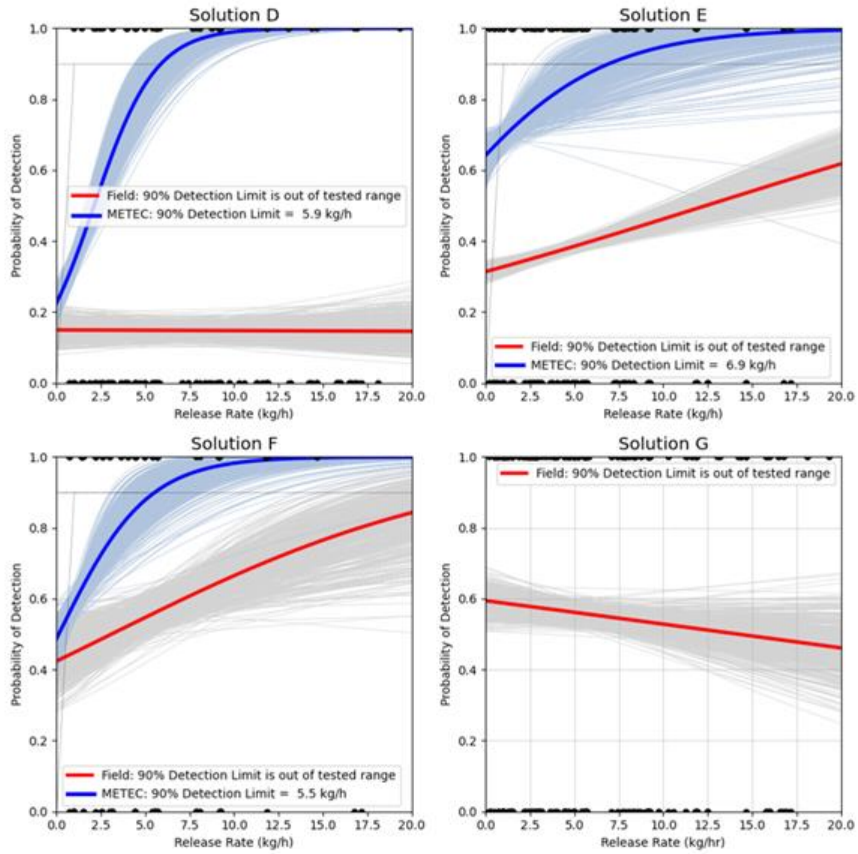

Figure 1 Probability of detection as a function of site rate estimates during CRs for all solutions during all deployments paired with their estimates made during METEC testing. The definition of detection, or a TP reading, for the field campaign includes any estimate above 0 kg/hr for solutions E, F, and D. As solution F does not have any 0 kg/hr estimates, the definition of detection is any estimate above 5.7 kg/hr, the assumed baseline for site rate estimates. Solution G did not participate in METEC testing.

METEC CR experiments indicated that POD was a function of release rate, assuming logistic function relationship. In the field campaign, solutions either displayed no dependence on CR rate (Solutions D or G) or did not display a trend that would identify 90% POD within the CR rates utilized, despite the largest CR rates being several times the estimated emissions from the facility (Solutions E and F). None of the solutions demonstrated a POD similar to that in METEC testing.

The design of the field campaign experiments should result in an increase in reported emissions when a controlled release is in progress (CR), relative to times with no controlled releases (NR). We analyze this using a confusion matrix approach. First, we compute the mean ($\mu_{NR,i}$) and standard deviation ($\sigma_{NR,i}$) of reports from each solution i when no controlled release was happening, considering all available NR data. A detection during a CR was defined as any emission estimate, $E_{CR,i} \geq \mu_{NR,i} + \sigma_{NR,i}$. The resulting confusion matrix is shown in Table 1.

Table 1 Legend of confusion matrix for detection of CR and NR data.

Detection Confusion Matrix		
	Not Releasing	*Controlled Releases*
Not Detected (Below Detection Threshold)	$E_{NR,i} < \mu_{NR,i} + \sigma_{NR,i}$	$E_{CR,i} < \mu_{NR,i} + \sigma_{NR,i}$
Detected (Above Detection Threshold)	$E_{NR,i} \geq \mu_{NR,i} + \sigma_{NR,i}$	$E_{CR,i} \geq \mu_{NR,i} + \sigma_{NR,i}$

The results of Table 1 exhibit that 98% of the NR estimates and 94% of the CR estimates were below the detection threshold, showing at least that there was an increase of detections during the CR testing. A chi-squared test with p-values above 0.05, showed no statistical significance in detection between periods with/without controlled releases in 14 of the 19 site and solution combinations.

Results of the confusion matrix could be driven by many factors. However, two primary factors are either (a) sensors did not respond to controlled releases, or (b) algorithms analyzing sensor data were unable to identify detections from sensor responses. This analysis utilizes the same definitions as the confusion matrix, now looking at time series of concentrations reported by the solutions' sensors.

Figure 2 provides an example of a controlled release enhancement analysis. The figure shows sensor activity with respect to the CR rates during times of low and high wind variability. Under ideal positioning and steady wind conditions specified by the solutions, a controlled release from a likely leak location occurring directly upwind of a CMPS shows a concentration enhancement where peak concentrations trend with different CR release rates (Figure 2, left panel). During varied wind directions the concentration enhancements do not trend with the CR release rate, and a period with no CR shows reading similar to periods with CRs (Figure 2, right panel).

The figure shows one example which is clearly analyzed. Other site-solution combinations displayed similar behavior with varying degrees of clarity. Qualitative results suggest that algorithms may need to consider multiple wind transport parameters to know when concentration enhancements are likely to occur, and over what upwind angle. In conditions falling outside these parameters, observations are unlikely to be indicative of emissions, and may need to be discarded.

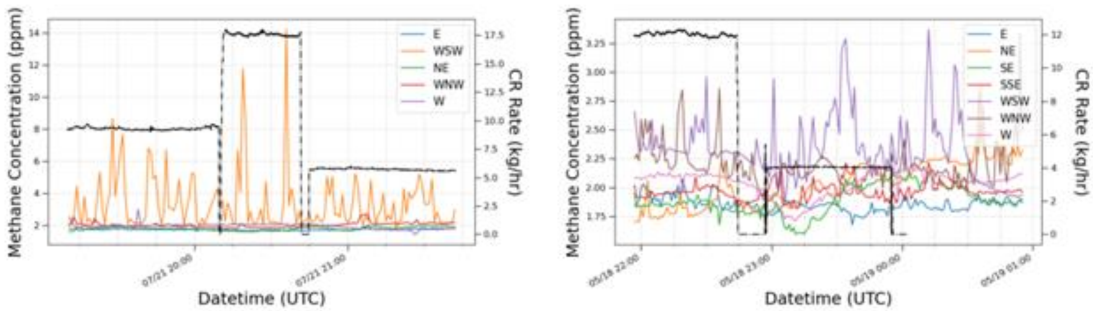

Figure 2 Left plot shows solution C's concentration estimates in comparison with the CR rates. The black dashed line shows the CR rate and the colored lines are solution measurements. At this time of CR the wind was coming from the NW and the downwind WSW sensor was seeing a clear increase and decrease. The right plot shows a contrast to that where solution C's concentration is scattered across all the sensors.

Research Plans

Beginning next year our team will be completing another field campaign on CMPSs with more focus on defining the baseline before conducting controlled releases using several techniques, including tracer studies, use of CSU's MAES calculations, hi-flow measurements, and optical gas imaging totals. The team's goal is to analyze what is occurring on the sites without controlled release tests to then analyze variances when controlled releases are conducted. Other continuous monitoring techniques will also be implemented with the CMPSs to identify the accuracy of the solutions to assist in progressing and unifying the procedures of detecting emissions on oil and gas sites.

Publications

I am currently submitting an article to preprint on the analysis of this field campaign and am co-author on "Using a driving survey to estimate the size of methane emission sources in the DJ Basin" which was submitted by Stuart Riddick of Colorado State University.

Literature cited

"Advancing Development of Emissions Detection." Energy Institute, Colorado State University, https://energy.colostate.edu/metec/aded/. Accessed August 16, 2022