Validation of RECON Advanced Mobile Leak Detection: Quantification Accuracy and Probability of Detection from Controlled Release Testing

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Abstract

Advanced Mobile Leak Detection (AMLD) is an increasingly important tool for natural gas utilities seeking to identify and quantify fugitive methane emissions from distribution infrastructure. However, confidence in these systems requires rigorous validation of both detection sensitivity and flow rate quantification accuracy under realistic field conditions. In this report, we present results from controlled release testing of Project Canary's RECON AMLD platform conducted at three testing facilities spanning distinct geographic regions and atmospheric conditions. Testing covered a wide range of conditions including above-ground and below-ground (buried pipeline) leak sources, release rates from 0.2 to 120 scfh, downwind distances from 0 to 250 feet, and both daytime and nighttime operation. At Colorado State University's Methane Emissions Technology Evaluation Center (METEC), Project Canary was the first solution provider to test mobile leak detection on newly installed buried pipeline infrastructure, enabling a detailed characterization of detection probability as a function of distance and release rate. Across all testing, 89% of estimated leak rates fell within a one order of magnitude band ($\pm\sqrt{10}\times$) of the actual flow rate. Probability of detection analysis from the METEC buried pipeline testing reveals that the system reliably detected all tested release rates (down to 1 scfh from buried infrastructure) across the full range of distances tested, with observed peak concentrations above the system's detection threshold even under the most challenging conditions (low-rate, long-distance, daytime).

1 Introduction

Natural gas utilities face increasing pressure from regulators, the public, and their own sustainability commitments, to identify and mitigate fugitive methane emissions from aging distribution infrastructure. Advanced Mobile Leak Detection (AMLD) technologies represent a significant improvement over traditional leak survey methods, offering the ability to not only detect leaks from a moving vehicle but also to estimate the emission rate of each detected source. This quantification capability is critical: it enables utilities to prioritize repairs based on emission magnitude, comply with emerging regulatory requirements, and track the effectiveness of their leak reduction programs over time.

Confidence in these estimates requires rigorous validation under realistic field conditions. To this end, Project Canary participated in an extensive series of controlled release experiments over the past year at three testing facilities to validate the detection and quantification performance of the RECON AMLD platform. These tests were designed to span a wide range of operationally-relevant conditions: three geographic regions with distinct atmospheric profiles (a high-altitude semi-arid environment in Colorado, a warm inland valley in central California, and a humid continental climate in the Northeast), both above-ground and below-ground (buried pipeline) leak sources, release rates spanning nearly three orders of magnitude (0.2 to 120 scfh), downwind distances from 0 to 250 feet, and both daytime and nighttime driving conditions. Notably, the METEC testing at Colorado State University included newly installed buried pipeline infrastructure, and Project Canary was the first solution provider to evaluate mobile leak detection on this facility. This buried pipeline testing is of particular relevance to the natural gas distribution sector, where the majority of fugitive emissions originate from subsurface infrastructure.

In the following sections, we first provide a brief overview of the RECON system and its measurement approach (Section 2), then describe the testing program and experimental design (Section 3). Sections 4 and 5 present a detailed analysis of detection performance from the METEC buried pipeline and above-ground testing, respectively. Section 6 presents the quantification accuracy results, first from the METEC campaign and then aggregated across all three testing facilities. Finally, Section 7 summarizes the key findings and their implications for utility AMLD programs.

2 System Overview

The RECON AMLD platform is built around an Aeris Technologies MIRA Ultra laser spectrometer, a mid-infrared absorption instrument capable of simultaneous, high-frequency measurement of both methane (CH_4) and ethane (C_2H_6). Operating in the mid-infrared, where methane and ethane absorption features are orders of magnitude stronger than in the near-infrared, the instrument achieves sub-ppb to low-ppb precision at 1Hz for both species (Liu et al., 2026 [1]). The dual-species measurement capability is a key differentiator: because biogenic methane sources (e.g., landfills, marshes, wetlands, agricultural operations) produce methane without significant ethane content, while thermogenic natural gas contains ethane at a characteristic ratio, the presence of ethane above a threshold serves as a reliable indicator that a detected methane enhancement originates from pipeline gas rather than a biogenic source. This substantially reduces the false positive rate in operational surveys, which is a persistent challenge for single-species methane detectors operating in areas with diverse methane source types.

The spectrometer is mounted in a survey vehicle along with a GPS receiver and an ultrasonic anemometer. The anemometer measures the apparent wind vector, from which the vehicle's motion (known from GPS) is subtracted to estimate the true ambient wind speed and direction. This wind information is critical for the quantification algorithm, which requires knowledge of the cross-wind component of the wind speed as the vehicle traverses through a methane plume.

The quantification approach follows the transect-integrated flux method (e.g., MacMullin and Rongère [2]), which has become a standard technique for mobile leak quantification in the natural gas sector. The fundamental idea is that as the vehicle drives through a methane plume, the product of the concentration enhancement above background and the perpendicular wind speed, integrated over the path of the vehicle's pass through the plume (transect), yields the horizontal mass flux through the measurement plane. This horizontal flux is then multiplied by an effective vertical mixing height to obtain an estimate of the total volumetric flow rate of the source. The effective height is informed by a combination of factors including atmospheric stability conditions and characteristics of the observed plume, and represents the most uncertain component of the quantification estimate, a challenge shared across all implementations of this method in the literature.

In a typical survey, the vehicle drives along roads adjacent to the pipeline infrastructure at normal traffic speeds. Multiple passes of the same road segments are performed in each direction, providing repeated independent measurements of any leak sources upwind of the vehicle's path. Detected plumes are geolocated, associated with nearby infrastructure, and nearby detections are clustered together. The quantification algorithm is applied to each individual detection to produce a flow rate estimate, and the estimates within each cluster are averaged to yield a single best estimate of the source rate.

3 Testing Program

Controlled release testing was conducted at three facilities, each offering distinct geographic, atmospheric, and infrastructure characteristics:

- **Colorado State University METEC** (Fort Collins, CO) — High-altitude semi-arid environment. Testing included both buried pipeline releases (from newly installed subsurface infrastructure) and above-ground releases. Day and night driving at distances from approximately 15 to 250 feet downwind. Release rates from 0.2 to 120 scfh. This was the most extensively tested site and is the focus of the detailed analyses in this report.

- **West Coast utility testing center** — Warm inland valley environment. Above-ground and below-ground releases at distances from 0 to approximately 80 feet downwind. Release rates from 0.5 to 24 scfh.
- **East Coast utility testing center** — Humid continental climate. Above-ground releases at distances from 0 to approximately 85 feet downwind. Release rates from 1.2 to 18.9 scfh.

At METEC, Project Canary was the first solution provider invited to test on the facility's newly installed buried pipeline infrastructure. This infrastructure consists of three pipeline segments (S1–S3), each approximately 20 meters long and separated by roughly 5 meters of undisturbed ground. The two active release points used in this study (S1 and S3) are buried at a depth of 3 feet beneath compacted, fine-sifted native soil, providing a realistic analog to in-service natural gas distribution mains. Testing was conducted over several days in late July 2025 with simultaneous releases at different rates from the two active sources. Because the sources are spatially separated along the pipeline, each downwind pass produces two distinct concentration peaks in the measurement time series, one from each source, with the peak height roughly proportional to the source's emission rate.

Release rate configurations were varied day-to-day, spanning from 1 to 120 scfh across the two active sources. The vehicle was driven in three concentric loop configurations at increasing distances from the pipeline, shown in Figure 1:

- **Inner loop**: approximately 10–45 feet
- **Middle loop**: approximately 45–100 feet
- **Outer loop**: approximately 100–200 feet

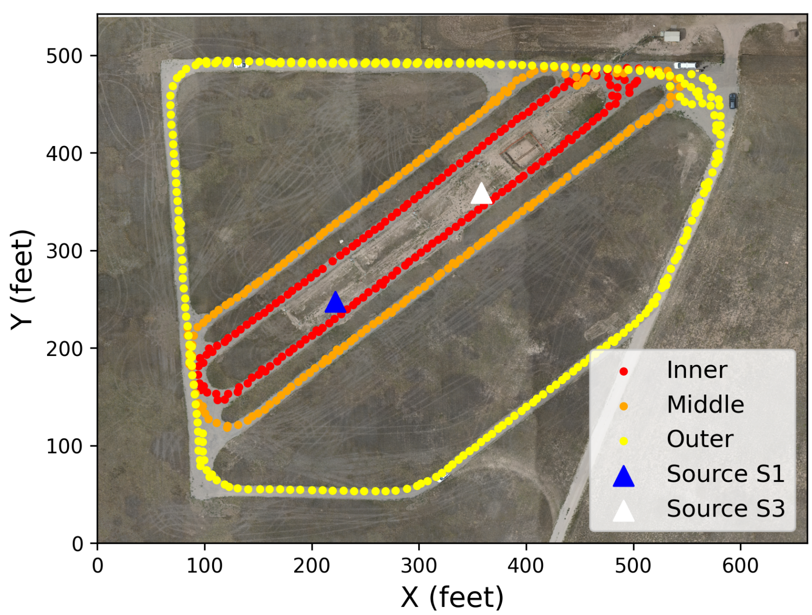


Figure 1: Drive loop configurations at the METEC buried pipeline testing facility. The inner (red), middle (orange), and outer (yellow) loops are shown relative to the two active release points (S1 and S3).

Each loop configuration was driven during both daytime and nighttime conditions to assess the impact of atmospheric stability on detection performance. The exact downwind distance for any given pass depends on the wind direction relative to the geometry of the encompassing loop (which is not circular), so the distances above represent approximate ranges. In addition to the buried pipeline releases, a series of above-ground point releases at rates as low as 0.2 scfh were conducted to probe the lower detection limit of the system, as the underground release infrastructure at METEC could not deliver rates below 1 scfh at the time of testing.

4 Probability of Detection: Buried Pipeline Testing

A primary objective of the METEC buried pipeline testing was to map out the probability of detection (POD) as a function of release rate and downwind distance. For each drive, individual passes of the pipeline were identified and each pass was scored as either a detection or a miss for each active source, based on whether a distinct concentration peak was observed at the expected spatial location. In total, hundreds of individual passes across multiple rate configurations, loop distances, and atmospheric conditions were used to compute the detection statistics presented in Section 4.3. The figures shown in this section are selected examples chosen to illustrate the character of the data at different distances and times of day, and are not the entirety of the dataset.

4.1 Nighttime Detection Performance

Under nighttime driving conditions, when the atmosphere is typically more stable and plumes are more coherent, RECON demonstrated excellent detection performance across all tested rate and distance combinations. Figure 2 shows an example from the inner loop at the lowest tested underground release rate configuration (1 and 5 scfh at the two active sources). The top panel displays methane concentration measurements overlaid spatially on an aerial image of the pipeline facility, while the bottom panel shows the corresponding time series with detected peaks marked. Each full pass of the pipeline produces two distinct concentration peaks corresponding to the two active release points, with the higher-rate source producing a taller peak. The peak ordering flips halfway through the drive when the vehicle reverses direction (i.e., goes from driving the loop clockwise to counterclockwise), while the relative magnitudes are preserved.

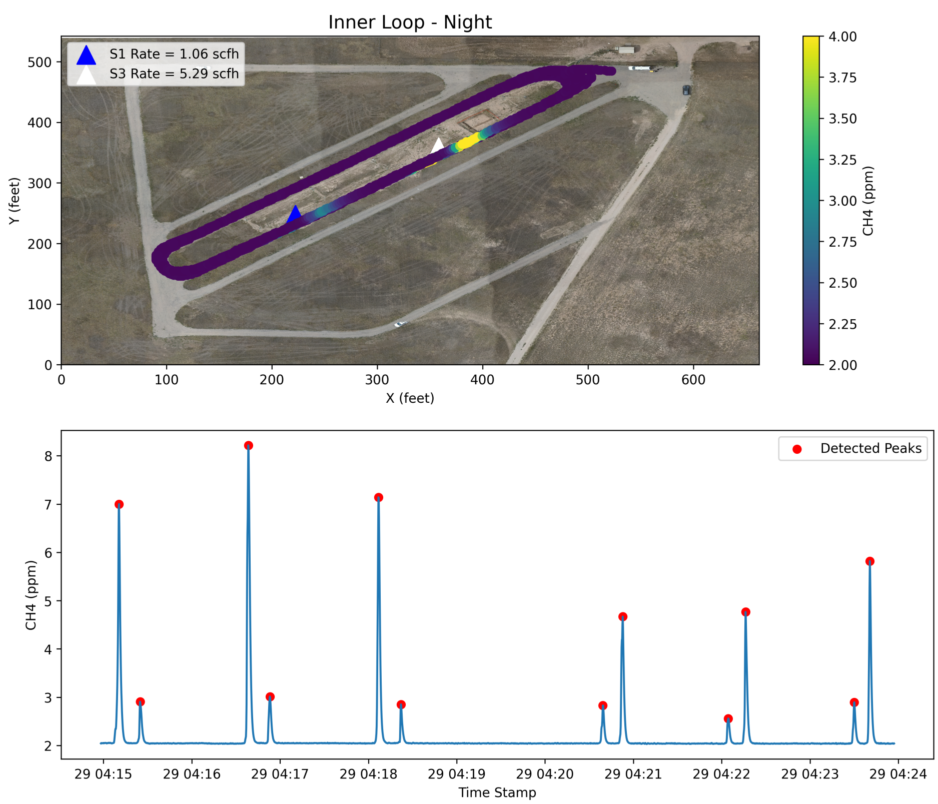


Figure 2: Inner loop nighttime measurements at the lowest tested underground release rate configuration (S1 at 1 scfh, S3 at 5 scfh). Top: spatial distribution of methane concentrations overlaid on an aerial image. Bottom: concentration time series with detected peaks marked in red. Both sources are clearly and unambiguously detected on every pass.

As the vehicle moves to larger distances on the middle and outer loops, the plumes have more time to disperse and the concentration enhancements decrease, but remain detectable. Figure 3 shows the outer loop measurements under the same release rate configuration. Even at distances of approximately 200 feet from the buried pipeline, both the 1 scfh and 5 scfh sources were detected with 100% efficiency during nighttime conditions.

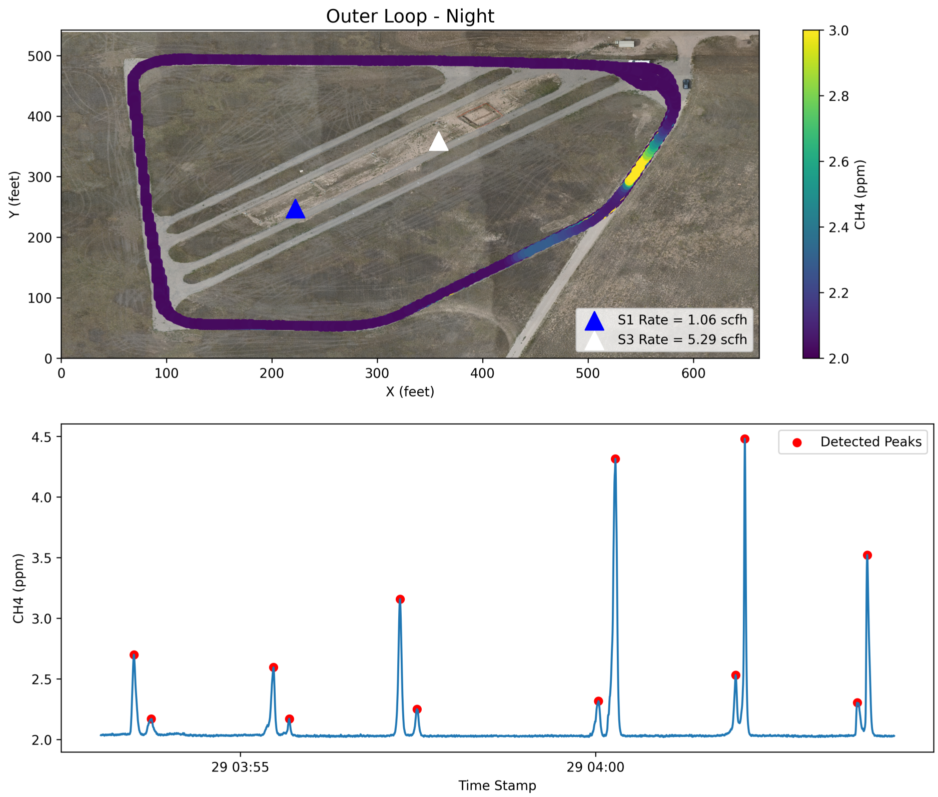


Figure 3: Outer loop nighttime measurements at the lowest tested underground release rate configuration. Despite the increased distance (approximately 200 feet for the prevailing wind direction during this drive), both sources are detected on every pass during nighttime conditions.

4.2 Daytime Detection Performance

Daytime atmospheric conditions are generally less favorable for plume detection. Solar heating of the ground surface generates convective mixing that disperses plumes more rapidly, reducing peak concentrations and broadening the spatial extent of the plume. This effect is well-understood in atmospheric dispersion science and represents a fundamental challenge for all mobile leak detection technologies.

An additional complicating factor during the METEC testing was that other testing activities at the facility during the daytime introduced background methane that interfered with the measurements. Despite these less favorable conditions, we observed good evidence that the system detected even the smallest release rates during daytime driving. Figure 4 shows the outer loop daytime measurements at the lowest tested release rate configuration, representing the most challenging combination of conditions tested: low emission rates, large downwind distances, and daytime atmospheric instability. Even under these conditions, both sources are clearly resolved as distinct peaks on the majority of passes, with some passes producing only a single merged peak, consistent with the expected effects of increased atmospheric mixing at larger distances. Overall, approximately 11 of 16 passes in this example show two-peak structure. All other drive and condition combinations (shorter distances, higher rates, nighttime atmosphere) exhibited equal or better detection performance.

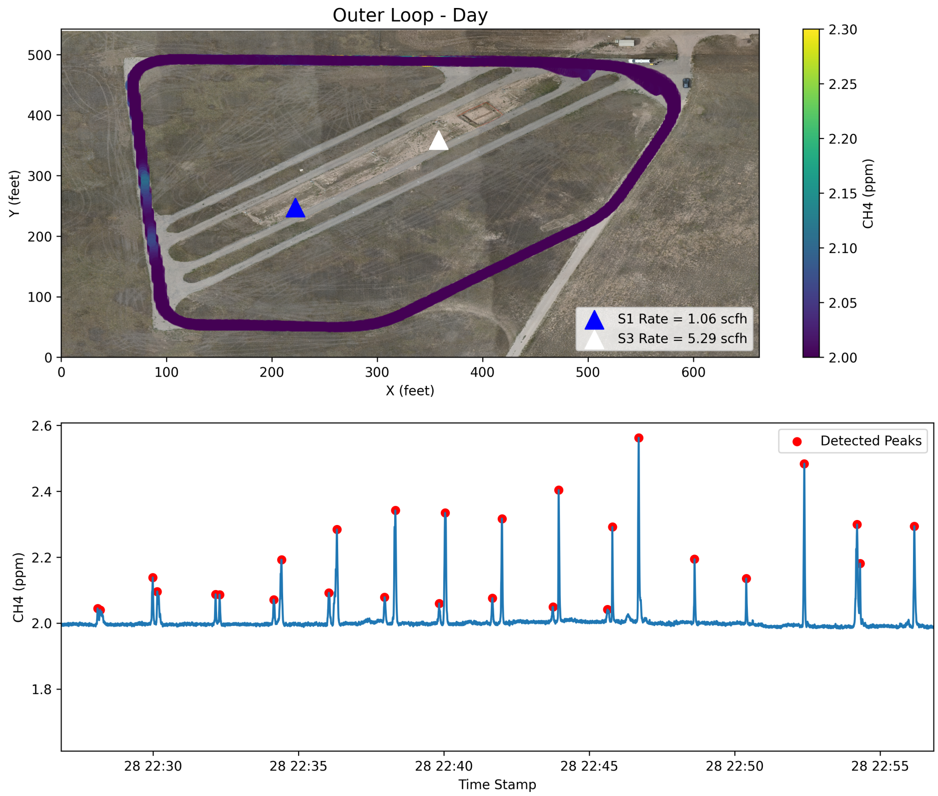


Figure 4: Outer loop daytime measurements at the lowest tested underground release rate configuration, the most challenging combination of conditions tested. Many passes show two distinct peaks corresponding to the two active sources, while some show only a single merged peak, illustrating the reduced but still effective detection performance under daytime atmospheric conditions.

4.3 POD Surface and Distance Dependence

By tabulating the detection outcome (hit or miss) for each individual pass across all rate and distance combinations, we computed a probability of detection surface as a function of release rate and downwind distance. Figure 5 shows this surface, computed from the full set of buried pipeline drive data.

A notable feature of this surface is that the POD is nearly independent of release rate: the dominant gradient runs along the distance axis, not the rate axis. In principle, we would expect detection efficiency to eventually degrade at sufficiently low emission rates, as peak concentration enhancements fall below the system's detection threshold. However, examination of the observed peak concentrations suggests that this limit was not reached during the testing campaign. Even at the outer loop distances (approximately 100–200 feet), the peak enhancements during nighttime drives for the lowest release rate (1 scfh) were in the range of 0.2–0.5 ppm, and the corresponding daytime peaks were roughly 0.1–0.2 ppm — well above the system's detection threshold of 35 ppb (0.035 ppm). This threshold, which defines the minimum concentration enhancement above background required to register a detection, is a configurable parameter in the RECON platform; 35 ppb represents the high-sensitivity setting recommended for most operational surveys, balancing sensitivity against robustness to background variability. The fact that observed peaks remained comfortably above this threshold at all tested rate and distance combinations indicates that the system was operating above its sensitivity floor throughout the campaign, and that the detection limit for buried pipeline leaks likely extends to distances and rates beyond the range tested here. The observed peak concentrations at the outer loop suggest that many of the missed detections at larger distances may be influenced by plume blending, where plumes from the two active sources overlap spatially and cannot be individually resolved. However, on any given pass, transient conditions such as wind shifts or turbulent dilution of the plume may also reduce the concentration enhancement below the detection threshold, resulting in a true missed detection.

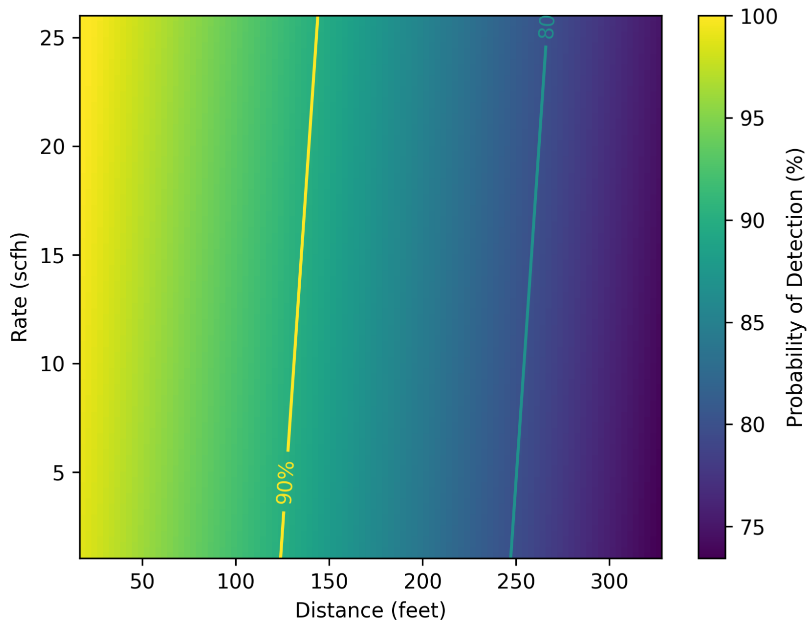


Figure 5: Probability of detection surface as a function of release rate and downwind distance, computed from all buried pipeline drive passes at METEC. Contour lines indicate 80% and 90% POD thresholds. The contours run nearly parallel to the release rate axis, indicating that detection efficiency depends primarily on distance rather than emission rate. Possible explanations for this behavior are discussed in the text.

The dual-species measurement capability of the RECON platform provides additional flexibility in setting detection thresholds. Because ethane co-detection can be used to confirm that a methane enhancement originates from pipeline gas rather than a biogenic source, the threshold can be set more aggressively without a corresponding increase in false positive rate. This effectively allows the system to operate at higher sensitivity than would be practical with a single-species methane detector.

5 Above-Ground Low-Rate Testing

The buried pipeline testing at METEC was constrained by the facility's minimum achievable release rate through the underground system, which was 1 scfh. To probe the lower detection limit more aggressively, a series of above-ground releases were conducted at rates as low as 0.2 scfh. For this testing, the underground releases were shut off; however, the ground in the vicinity of the pipeline appeared to be saturated with methane from the prior underground releases and continued to express residual gas, creating a non-trivial background signal.

Despite this background interference, the 0.2 scfh above-ground release was clearly detected at inner loop distances (less than approximately 30 feet) and detected on the majority of passes at middle loop distances (approximately 45–75 feet), as shown in Figure 6. At the outer loop distances (greater than approximately 125 feet), the plumes are wide enough that there is significant spatial overlap between the residual underground background and the above-ground source, making it ambiguous whether a missed detection is due to the system's sensitivity limit or the inability to spatially resolve the low-rate source from the overlapping background. We emphasize that these above-ground low-rate results have not been incorporated into the POD analysis presented in Section 4, which was conducted exclusively for below-ground pipeline releases. The reason for this exclusion was twofold: first, the spatial proximity of the central above-ground source to the neighboring underground sources made it nearly impossible to interpret a "missed" detection as being due to a true "miss" (the measured enhancement falls below the detection threshold) as opposed to the plumes blending. Second, whether a source is above or below ground may influence the expression of the signal and result in different detection statistics. As such, mixing together detection statistics from a handful of above-ground

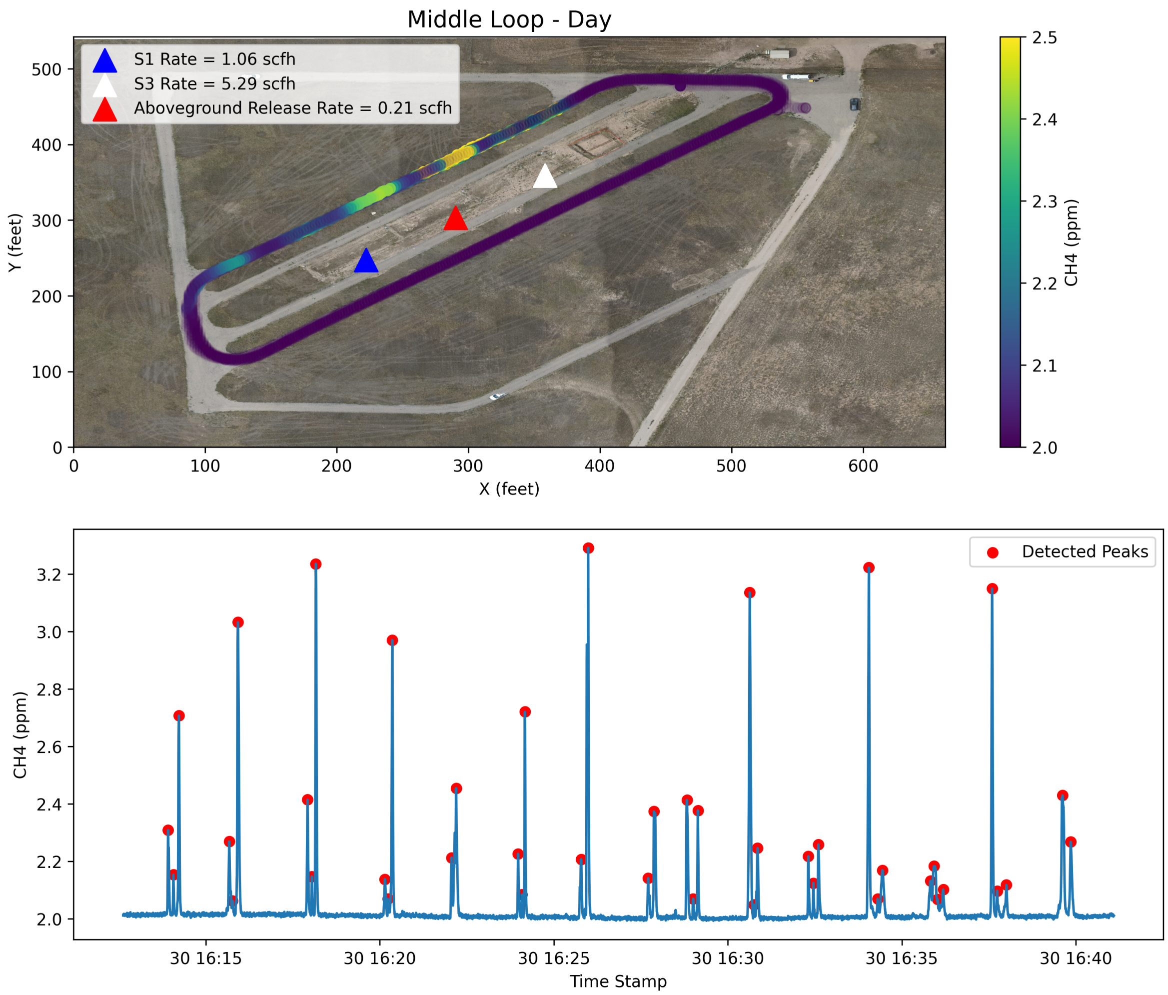


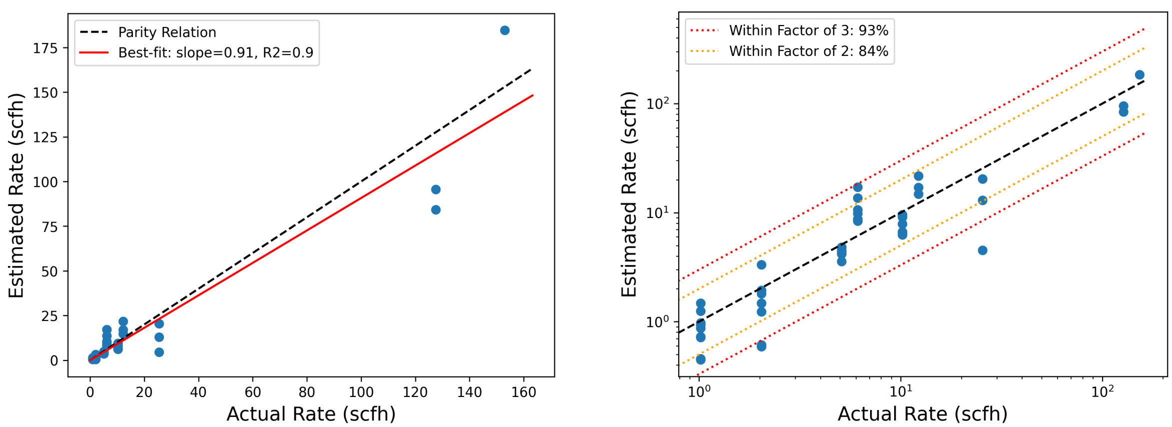
Figure 6: Middle loop measurements during above-ground low-rate testing (approximately 45–75 feet downwind). Underground releases were shut off, but residual methane from the previously saturated ground is visible as background peaks associated with S1 and S3. The 0.2 scfh above-ground release is visible as a distinct peak between the two residual underground source peaks on the majority of passes.

releases into a dominantly below-ground experimental matrix may skew the results. The key takeaway from this testing is that RECON demonstrates sensitivity to emission rates well below 1 scfh under favorable conditions, though rigorously characterizing the detection limit at these very low rates would require testing in the absence of confounding background sources.

6 Quantification Performance

6.1 METEC Buried Pipeline Quantification

Quantification performance at METEC was assessed across all drives, including both daytime and nighttime conditions. For each drive, detected plume transects were associated with the known source locations in a self-consistent manner, and the transect-integrated flux quantification algorithm was applied to produce a flow rate estimate for each source on each pass. These per-pass estimates were then averaged across all passes within a given drive for each source, yielding a mean estimated rate that can be compared to the known actual release rate. We note that the daytime drives are subject to additional scatter due to the previously-described background interference and less stable atmospheric conditions. Figure 7 shows the estimated versus actual rates on both linear and logarithmic scales. On the linear scale, we observe generally good correspondence between estimated and actual rates, with a best-fit slope through the origin of 0.91 and an R^2 of 0.90. On the logarithmic scale, we see that 93% of the estimates fall within a factor of 3 of the actual rate, and 84% fall within a factor of 2.



(a) Linear scale

(b) Logarithmic scale

Figure 7: Quantification results from METEC buried pipeline testing across all daytime and nighttime drives. (a) Linear scale with parity line (black dashed) and best-fit line through the origin (slope = 0.91, $R^2 = 0.9$). (b) Logarithmic scale with factor-of-2 (orange dotted) and factor-of-3 (red dotted) bounds. 93% of estimates fall within a factor of 3; 84% within a factor of 2.

6.2 Combined Quantification Results Across All Testing

To evaluate the overall quantification performance of the RECON system across diverse conditions, we aggregated the results from all three testing campaigns: the METEC buried pipeline testing, the East Coast utility testing center, and the West Coast utility testing center. This combined dataset spans release rates from 0.5 to 120 scfh across three distinct geographic and atmospheric environments.

Figure 8 shows the combined results on a logarithmic scale. Following the convention established by the NYSEARCH technology evaluation program [3], which assessed quantification accuracy using a $\pm\sqrt{10}\times$ band (approximately a factor of 3.16) and reported 77% of estimates falling within this range; we evaluate our combined results against the same metric. 89% of RECON's estimates fall within the $\pm\sqrt{10}\times$ band. We note that these numbers are not directly comparable due to differences in testing protocol, release configurations, and environmental conditions, but the NYSEARCH metric provides a useful common framework and benchmark for evaluating mobile leak quantification performance.

It is worth noting that the scatter in individual quantification estimates is inherent to any transect-integrated flux measurement approach. The dominant sources of uncertainty include variability in the true wind field at the point of plume transport (which may differ from the wind measured at the vehicle), turbulent fluctuations in plume structure, and the estimation of the effective vertical mixing height. Despite these sources of variability, the low bias of the system means that when multiple measurements are available, the mean estimated rate converges toward the true value.

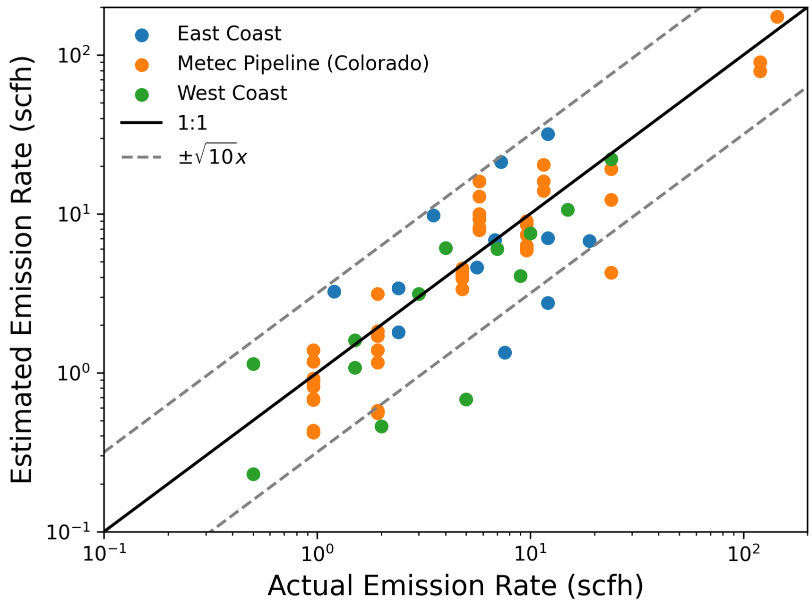


Figure 8: Combined quantification results across all three testing facilities on a logarithmic scale. The $\pm\sqrt{10}\times$ band is depicted with dashed gray lines. 89% of estimates fall within this range.

7 Conclusions

We have presented results from an extensive controlled release validation campaign for Project Canary's RECON AMLD platform, spanning three testing facilities, diverse atmospheric conditions, and release rates covering nearly three orders of magnitude. The RECON system detects buried pipeline leaks at rates as low as 1 scfh (the minimum rate achievable by METEC's underground infrastructure) with high reliability. During nighttime conditions, detection efficiency was 100% at distances up to approximately 200 feet. During daytime conditions, detection is noisier but still generally effective, with both sources resolved on the majority of passes even under the most challenging combination of conditions tested (lowest rates, largest distances, daytime atmosphere). The probability of detection is nearly independent of release rate across the range of conditions tested, and falls off primarily with distance. While we would expect detection efficiency to eventually degrade at sufficiently low emission rates, analysis of observed peak concentrations indicates that even at the outer loop distances, the system was operating above its sensitivity floor, i.e., the rate-dependent falloff was not reached during this campaign. Above-ground releases as low as 0.2 scfh were still detected at short and moderate distances, though characterizing the precise detection limit at these low rates was confounded by residual methane background from the prior underground testing.

Taken together, with 89% of estimated rates falling within a $\pm\sqrt{10}\times$ band of the actual rate across all testing, and reliable detection performance across a wide range of distances, release rates, and atmospheric conditions, these results demonstrate that RECON provides reliable and accurate leak detection and quantification under conditions representative of utility AMLD field operations. The dual-species measurement capability (methane and ethane) provides an additional layer of confidence by enabling thermogenic fingerprinting to reduce false positives from biogenic sources: a feature that was not directly tested in these controlled release experiments but represents a significant operational advantage in real-world surveys where biogenic methane sources are common. We believe these validation results provide a strong foundation for utilities evaluating AMLD solutions and for regulators seeking to understand the current state of the art in mobile leak quantification technology.

Data Availability

Raw measurement data are available upon reasonable request.

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