Controlled release experimental methods: 2021 Stanford controlled releases in TX and AZ

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1. Introduction

Due to increasing concern regarding methane emissions from oil and gas operations, a variety of mobile detection technologies have been developed. Some of the most promising of these technologies are airplane- and satellite-based technologies, which can survey large areas of land rapidly. Public, independent, and blind tests are key to establishing the effectiveness of these technologies.

For this reason, Stanford University conducted a series of controlled releases in 2021. These releases aimed to test a variety of airplane- and satellite-based detection methods at large release rates similar to those observed in the field. These methods are developed as an extension of the methods described in Ravikumar et al. [1] and Sherwin et al. [2].

2. Experimental setup

We conducted methane controlled release testing at two locations in summer and fall of 2021. The first deployment, from July 27-August 4, 2021, was located in Gardendale, Texas, near Midland, at coordinates [32.053111°, -102.300687°]. The second deployment, from October 14-November 4, 2021, was located in Ehrenberg, Arizona, at coordinates [33.630637°, -114.487755°]. In both cases, gas release equipment was provided and operated by Rawhide Leasing [3].

2.1. Gardendale Texas, July and August 2021

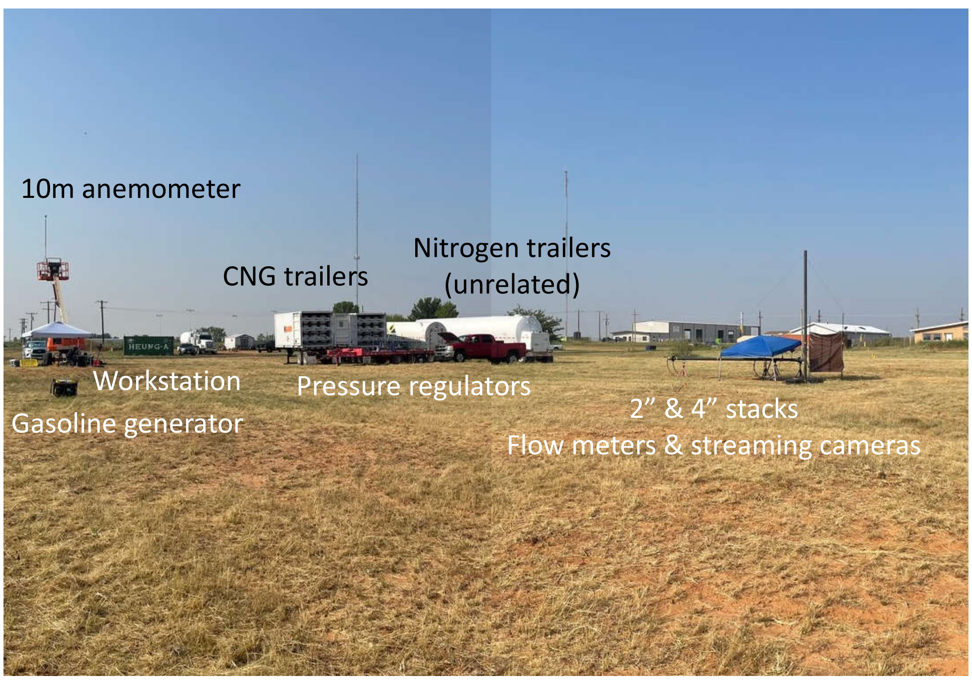

Figure 1. Overview photo of general Texas experimental setup and layout. Distance between workstation and stacks is 33.5 m (110 ft)

Figure 2. Gardendale testing location at lat-long [32.053111°, -102.300687°] Source: Google Maps

The testing location in Gardendale, TX is shown in an aerial photo (Figure 2) and in an overview ground photo (Figure 1).

The TX testing location included the following key components:

1. Two compressed natural gas trailers, each with its own pressure regulation and gas heating unit
2. Two release stacks (2 inch and 4 inch) with inline QuadraTherm 640i flow meters
3. Streaming video cameras to pass meter digital readouts to our workstation without requiring personnel to be near the gas release stack during releases.
4. Two-dimensional ultrasonic flow meter (Gill Instruments WindSonic 60) at 10 m above ground level
5. Infrared camera (FLIR GF320) continuously recording stack flows and broadcasting to workstation
6. A workstation with computers for data logging and recording

2.1.1. <u>Compressed natural gas trailers</u>

As in Sherwin, Chen et al. [2] and Ravikumar et al. [1], we used compressed natural gas (CNG) as the methane source for these controlled releases. We simultaneously contracted two CNG tube trailers, each with rated capacity 120 mscf and working capacity 100 mcsf for our releases. Trailer pressure varied from ~2,500 to ~500 pounds per square inch gauge (psig) depending on remaining gas levels. While the maximum pressure allowable in the trailer was 3600 psig, we did not fill trailers to the maximum pressure level. Instead, trailers were generally filled to ~2500 psig, depending on the day and expected release volumes. By reducing the starting pressure, capacity of the trailers was reduced, but excessive Joule-Thomson cooling was mitigated by reducing the expansion ratio between the compressed and atmospheric conditions. While this increased cost of gas refills due to increased numbers of driver refill days required, it allowed for more flexibility in flow rates without approaching the meter minimum temperature.

Figure 3. Pressure regulator with CNG trailers in background. Pictured are catalytic heater for regulator, pressure relief valve, and pressure gauges upstream and downstream of regulator. (Unrelated liquid nitrogen trailer to the right).

2.1.2. Pressure regulators

We used two Tescom pressure regulators, one per CNG trailer to manually control natural gas flow levels and reduce gas pressure in an orderly fashion. This was used to reduce gas pressure from trailer pressure (variable) to 250 psig or below (with steady pressure drop on route to the release stacks). The residual 250 psig pressure allowed for flow from the regulator to the stack along the 25-foot rubber hoses, and also enabled rapid exit from the stack to promote lofting of the gas plume. To reduce cooling of the regulators, a catalytic heater partially compensated for the Joule-Thomson cooling effect introduced by the pressure drop. 1-inch rubber hoses conveyed the gas from the regulator to the steel pipe release stack and metering setup.

Rawhide Leasing personnel operated flow controls from the pressure regulators, responding to hand signals from Stanford personnel at the workstation.

2.1.3. Release stacks

We used two separate release stacks to allow a wide range of flow levels.

The first release stack had a 2-inch diameter, with a release point 3 meters (115 in) above ground level. The vertical release stack connected to horizontal straight pipe with the QuadraTherm meter. The meter was located with 1.46 m of straight pipe upstream of the meter, and 0.52 m of pipe downstream (i.e. between the meter and the release stack) (Figure 4). This configuration allowed us to comply with manufacturer recommendation that the meter be located with 40 pipe-diameters upstream and at least 5 diameters downstream to eliminate effects of turbulent flow on the meter reading [4]. The 2-inch release stack accepted only a single 1-inch hose from the pressure regulators. The maximum release rate from this stack, limited by the rated full scale of the meters, was 27,960 scfh (~540 kgh assuming incoming gas is 85% methane). See below for detailed description of meter full scale flow rates as a function of meter type and pipe diameter.

The second stack had a 4-inch diameter, with a release point 5.25 m (206.5 in) high. The meter was located with 5.7 m (223 in) of straight pipe before the meter and 0.76 m (30 in) after the meter (Figure 4), also satisfying upstream and downstream requirements for proper flow measurements [4]. The 4-inch release stack accepted up to two 1-inch hoses from the pressure regulators to enable higher flow rates drawing from both trailer simultaneously. The maximum release rate from this stack, limited by the rated full scale of the meters, was 106,080 scfh (~2,000 kg CH_4 per h assuming incoming gas is 85% methane).

In both cases, we used 640i QuadraTherm meters with serial numbers 162928 and 218645.

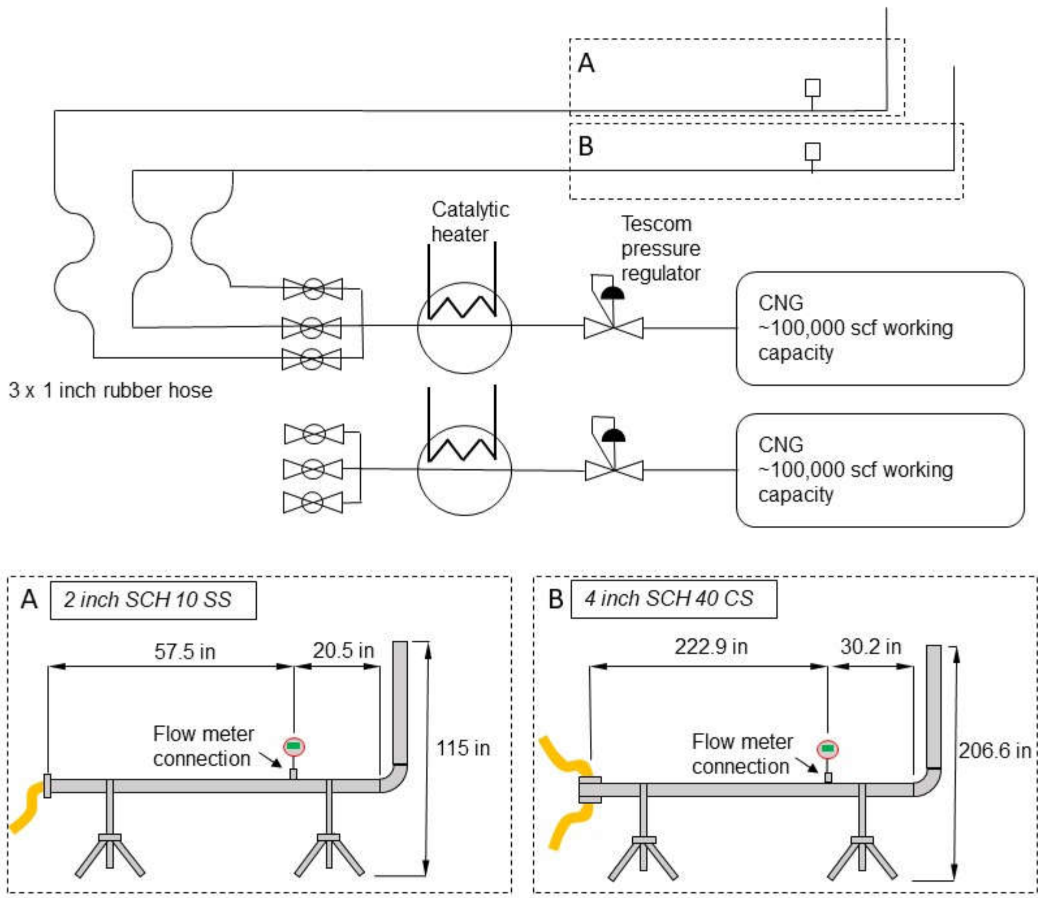

Figure 4. Piping and instrumentation diagram for controlled release apparatus in Texas. Note that the catalytic heater was in direct contact with the Tescom pressure regulator.

2.1.4. Data transmission and recording

Due to supply chain delays leading up to TX site releases, our full data gathering and recording apparatus was not available until our AZ campaign (see description below). For this reason, the on-meter digital displays were used to transfer data to our workstation. Zoom webconferencing iPhone (tripod-mounted) provided real-time meter readings to Stanford personnel at the nearby workstation, and the video records were saved to online backup automatically. To improve video quality, we installed a brown tarp in the camera background and installed a mounted umbrella as a shading device. Optical character recognition with manual validation of generated numerical readings was performed to extract meter readings from the saved video streams.

Figure 5. Release stacks and piping upstream of meters. Shown are 2" (left) and 4" (right) release stacks for natural gas. Meter digital readouts were livestreamed to control station via smartphone. Brown tarp and black umbrella improve contrast and visibility for the video livestream.

2.1.5. Anemometer

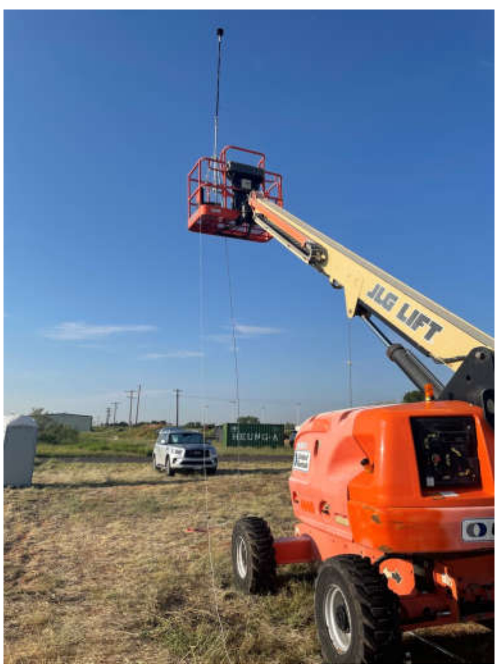

Figure 6. Boom lift including 4 m pole mounted tripod which holds sonic anemometer. Cable returns signal to dedicated wind monitoring laptop.

To measure wind speed 10 m above ground level, we deployed a Gill Instruments WindSonic 60 2-dimensional ultrasonic anemometer on a 4 m pole-mounted tripod. Tripod was secured (6x ½ inch bolts) to the steel flooring of a JLG 400s telescopic boom lift bucket. The boom lift bucket is designed for vertical lift while keeping the platform level, and fine adjustments to height could be made. Anemometer is placed ~40 m S-SE from the stack and ~25 m E of the trailers.

2.1.6. Workstation

Figure 7. Stanford workstation with FLIR infrared camera. Workstation situated 33.5 m (110 ft) from release stack and ~25 m from regulation trailer.

The Stanford researcher workstation, next to the anemometer, was the operational center of the releases. Key equipment at the workstation included a Zoom livestream of flow meters, real-time anemometer readings, FLIR infrared camera footage for safety monitoring, and supplementary laptops and smartphones for real-time flight tracking, data logging and operational planning.

The workstation, flow meters, and smartphone video streaming were all powered by a gasoline-powered generator situated >25 m from the release stack and trailers.

2.1.7. Safety

All work involving equipment setup, pipe installation and adjustment, flow meter installation, gas flow rate adjustment, and attaching of gas trailers to equipment was performed by trained Rawhide personnel. All gas was odorized allowing for detection of leaks or other accidental discharges.

Rawhide personnel followed all applicable safety protocols including daily leak checks using olfactory and bubble solution methods. As required by Stanford approved safety protocols, Stanford researchers did not control any gas release equipment and maintained a distance of 30 m from the release location during releases.

Additionally, the FLIR camera was trained on the release stack and recording during releases. The live video display was continuously playing during releases and was monitored by researchers in real time. The gas is easily visible on the FLIR instrument, and the state of lofting and dissipation is clearly visible. Additionally, the Stanford researchers were continuously attentive to olfactory signals (smells) from gas odorant. Because of the high stack exit point, the buoyant nature of the natural gas, the rapid gas exit velocity, and the large distance between the stack and the control station, odorant was rarely detected by the researchers over the test period.

2.2. Ehrenberg Arizona, October and November 2021

The Ehrenberg Arizona location was designed to allow for larger releases and more automated data collection.

Figure 8. Overview photo of Arizona experimental setup. Stack is ~45 m from LNG trailer and ~45 m from workstation and anemometer.

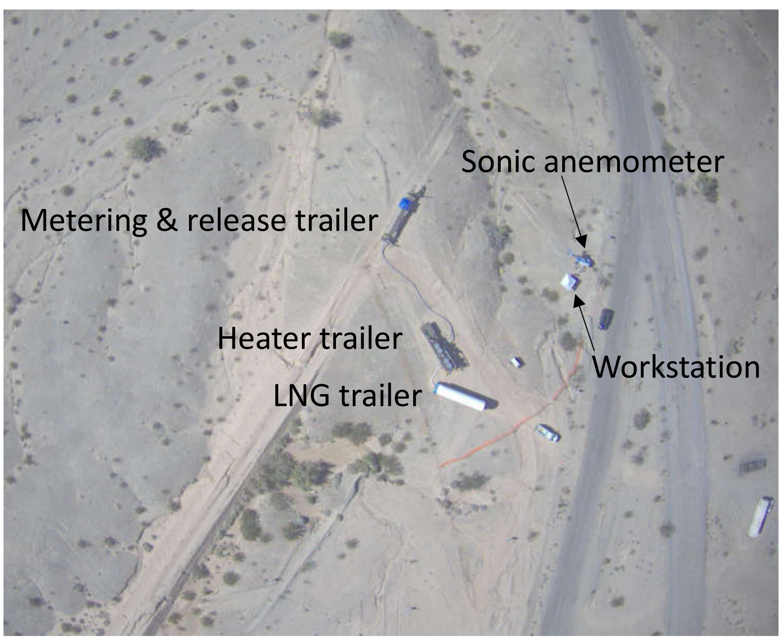

Figure 9. Ehrenberg testing location [courtesy of Bridger Photonics Inc.]

The Arizona testing location contained the following key components:

1. A liquefied natural gas trailer
2. A heater trailer to reheat the liquefied gas to atmospheric temperature and regulate output pressure
3. Two Sierra Quadratherm 640i meters, including a newly factory calibrated meter that was obtained between the TX and AZ releases

4. One MicroMotion coriolis meter that measured smaller flows on the 0.5 inch pipe.
5. Metering and release trailer with 0.5, 2, 4, and 8 in. diameter metering pipes fitted with, with inline meters. Meters were connected via Nanodac automatic data logger which recorded 4-20mA signals from the meters via cable. As a redundancy measure, we also livestreamed meter digital readouts via Zoom to our workstation, as was performed in TX campaign.
6. A Gill Instruments WindSonic 60 2-dimensional ultrasonic anemometer at 10 m above ground level
7. A workstation with computers

2.2.1. Liquefied natural gas trailer

Figure 10. Liquefied natural gas trailer. Trailer stores ~900 mscf (17-18 tonnes) of gas at approximately 150 psig and -162 °C.

Due to the high maximum target volume needed to accommodate satellite testing we opted for a high-capacity liquefied natural gas (LNG) trailer to supply methane. The trailer's capacity is 892,300 scf of capacity, including roughly 800,000 scf of working capacity (~16 tonnes of working capacity). LNG is stored in the insulated trailer at ~ −162 °C (−260 °F), but at relatively low pressure [150 psig]. This configuration allowed for more reliable heating of the gas to required temperatures because of reduced Joule-Thomson cooling upon gas expansion.

2.2.2. Heater trailer

Figure 11. Heater trailer for phase change of liquified natural gas back into gaseous state. Cold frost-covered white hose on left brings cold LNG from LNG trailer to heater trailer. Large diameter hose on right brings warmed LNG to release and metering trailer.

A separate heater trailer is required to ensure reliable phase change of the liquified gas into gas phase at our required flow rates while maintaining an acceptable downstream temperature for the gas meters. Sierra Quadratherm 640i meters are rated for minimum temperatures of -40°F (-40°C [5]), so significant warming above the boiling point of LNG (~ - 162°C) is required and may not reliably be obtained from atmospheric heat transfer depending on flow rates and conditions. The heater trailer combusts small quantities of natural gas to heat glycol, which is used to reheat LNG via a heat exchanger.

2.2.3. Metering and release trailer

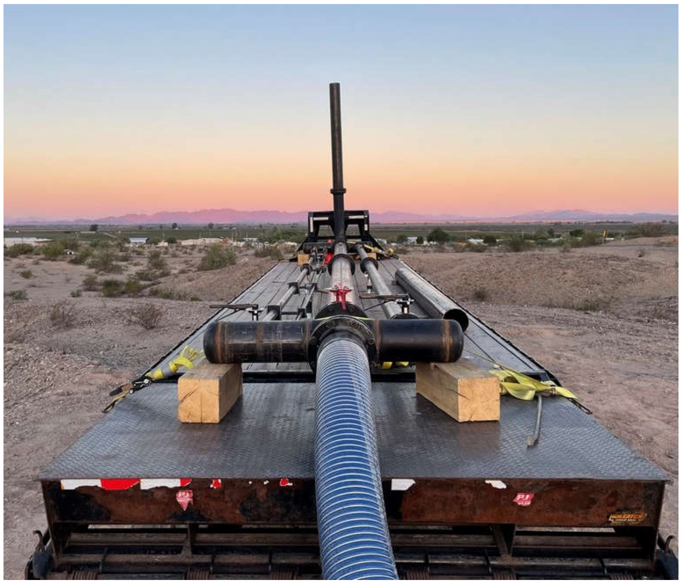

Figure 12. Metering and release trailer, seen from inlet side where large diameter hose attaches from heater trailer to metering pipes. Metering pipes (from left to right) include 2 inch, 0.5 inch, 8 inch, and 4 inch. All pipes are standard schedule 40 diameter steel piping. Straight run of 8.5 m on the trailer before the meters assures reliable measurements due to required 40 upstream straight run diameters.

After reheating and pressure regulation, gas flows through an 8-inch hose for approximately 100 ft (30 m) to the metering and release trailer. The metering and release trailer consist of a flow splitter, and shutoff valves controlling flow into four parallel pipes of 0.5 inch, 2 inch, 4 inch, and 8 inch schedule 40. Pipes include inline metering near the release stack, with all gas exiting through a common 8-inch stack at 3.8 m above ground level.

All meters had 8.5 m of straight pipe before the meter, equivalent to 42 pipe diameters for the 8" pipe. All meters had 1.2-1.3 m of straight pipe after the meter, equivalent to 5.75 pipe diameters for the 8" pipe (Figure 13). In all cases, this exceeds manufacturer recommendations for reliable flow measurements (following manufacturer recommendations of 40 upstream diameters followed by at least 5 downstream diameters [4]).

Rawhide Leasing personnel operated flow controls from the base of the release trailer, responding to hand signals from Stanford personnel at the workstation.

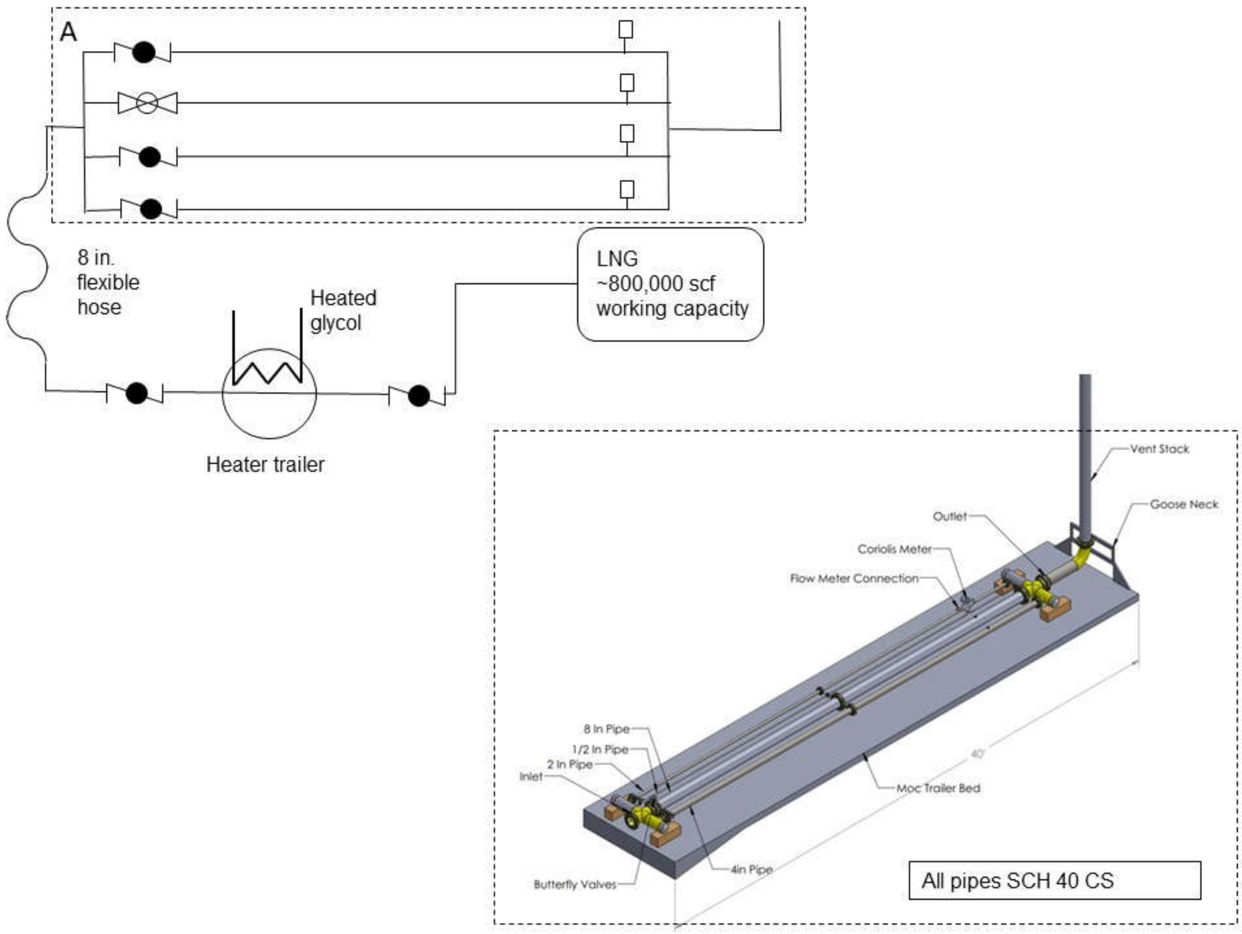

Figure 13. Piping and instrumentation diagram for controlled release apparatus in Arizona (inset diagram courtesy of Volta Fabrication).

2.2.4. Anemometer

Figure 14. Boom lift including 5.2 m pole mounted tripod which holds ultrasonic anemometer. A cable (not shown) returns signal to dedicated wind monitoring laptop.

To measure wind speed 10 m above ground level, we deployed a Gill Instruments WindSonic 60 2-dimensional ultrasonic anemometer on a 5.2 m pole-mounted tripod in the bed of a Genie S-40 boom lift. Note that although the boom lift was on terrain roughly level with the release apparatus, the surrounding terrain was uneven, with gullies resulting in local declines in elevation of as much as 3 m. This may introduce additional uncertainty into interpretation of 10 m winds.

2.2.5. Workstation

Figure 15. Stanford workstation with FLIR infrared camera. Workstation situated ~45 m from release stack and 40 m from regulation trailer.

The Stanford researcher workstation, next to the anemometer, was the operational center of the releases. Key equipment at the workstation included the readout of the Nanodac automatic data logger attached to the meters to laptop, simultaneous Zoom livestream of flow meters, real-time anemometer readings, FLIR recording of stack and trailer, and supplementary laptops and smartphones for real-time flight tracking, data logging and operational planning.

For much of the testing, the FLIR infrared camera was filming at the workstation, although we also collected footage from other angles. This footage served as a safety measure to track gas flow while producing additional valuable data.

Figure 16: Example footage of release plume captured using FLIR infrared camera

The workstation, flow meters, and smartphone video streaming were all powered by a gasoline generator.

3. Experimental procedures

3.1. Survey Design and Survey Protocol

In advance of testing, Stanford collaborated with Colorado State University to develop a standardized aerial test protocol for consistent testing of leak quantification solutions [8]. The protocol contains guidelines for operator participation in the controlled release study. Briefly, the guidelines ask operators to conduct measurement acquisition using operations as close as possible to commercial or research field operations. Any deviations were asked to be reported. For example, operators were encouraged to provide Stanford with coordinates of the planned overpass tracks ahead of time. We also generated a system for standardized data reporting. Included in the survey protocol bundle was a spreadsheet with sections for “Performer Info” and a “Survey Summary”. The “Performer Info” tab was filled out by teams in advance of the trials with details of the sensor technology, software used, expected survey time and altitude, and approach for wind measurement, etc. The “Survey Summary” tab contains a standardized template for reporting emission estimates, wind estimates, and associated uncertainty.

3.2. Sampling approach

Stanford personnel delivered a range of sustained release levels of varying duration to participating airplane teams, seeking to maximize sampling of as wide and complete a range of levels as possible. We under-sampled the largest release levels relative to smaller levels in part due to cost and gas holding capacity constraints. At the largest rates performed (1.7 tonne/h in TX, 7.4 tonne/h in AZ) the amount of gas consumed is large and the cost is high. Therefore, these largest releases were performed sparingly and often in concert with satellite overpasses.

3.3. Setting and changing release levels

In both Texas and Arizona, Stanford personnel directed Rawhide personnel to set methane release levels via hand signals, using the video livestream of the meters to ensure releases remained stable within the targeted range. In instances in which levels fell below the targeted range, Stanford personnel requested adjustments to release rates to bring levels within range.

When changing release levels for airplane teams, Stanford sought to rapidly shift to and stabilize at a new level ~30 seconds after the airplane had passed overhead, starting after the image is obtained. This then allows for maximal plume time formation. This target is generally achievable, as illustrated in the flow rate time series shown in Figure 22.

The automated flow valve positioner that is typically used in this setup was not functional and unable to be replaced on the timeframe of the study due to numerous supply chain shortages and challenges encountered. This resulted in hand operation of the flow valve by Rawhide personnel. In general, hand operation of the flow valve worked well, but in some cases the desired flow rate was overshot and correction was required.

3.4. Data recording procedure

For additional layers of redundancy, data was recorded by automated dataloggers and simultaneous real-time readings via hand recording and screenshots. This includes timestamped written field measurements of the gas release rate and wind speed at each airplane overpass, when the airplane is directly over the stack. This is accomplished via tracking the moment of overflight via visual inspection, supplemented by the FlightRadar24 application.

This redundancy proved useful. For example, on July 31st a data transmission failure in TX resulted in poor quality output of zoom recording, and real-time screenshots provided confirmation of the release quantities.

4. Quadratherm 640i meter validation and comparison

4.1. Meters used in tests

Figure 17. Two Sierra QuadraTherm 640i meters installed in the 2 inch (left) and 8 inch (right) pipes in Arizona. The tarp above these meters is for shading to reduce glare and improve contrast for the video livestream.

Three meters were used in this experiment. All three meters were Sierra Quadratherm 640i thermal flow meters. These insertion-style meters [5], designed to fit into pipe of various diameters given the correct fitting. The three meters were purchased in 2016, 2018, and 2021. The properties of the three meters are as follows:

2016 meter: Owned by contractor Rawhide Leasing Inc. Purchased 2016. Serial number 162928. Used in various previously published tests (Ravikumar et al. [1], Sherwin et al. [2]) as well as internal testing by Kairos Aerospace. Last factory calibrated June 8, 2015, with recalibration suggested by June 8, 2017. Factory calibrated against air, translating to other gasses via correlation factors. Methane is included using gas selection feature "8", which indicates factory calibration against air.

2018 meter: Owned by contractor Rawhide Leasing inc. Purchased 2018 as part of Ravikumar et al. [1] "Mobile Monitoring Challenge" experiments and used in other tests as well (e.g., Sherwin et al. [2]). Serial number 218645. Last factory calibrated May 11, 2018, with recalibration suggested by May 11, 2020. Calibrated against methane directly within factory (gas selection feature "8A").

2021 meter: Owned by Stanford University (Brandt lab group). Purchased September 2021. Serial number 308188. Factory calibrated on October 27, 2021 before shipping directly to AZ test site (suggested recalibration by October 27, 2023). Calibrated against methane directly within factory (gas selection feature "8A").

4.2. Quadratherm meter installation

Sierra Quadratherm 640i meters are insertion meters. These meters are placed into a ¾ in. compression fitting which welded into the topwall of the pipe. The meter is inserted to the proper depth to ensure that the bottom of the longest meter probe tip is ½ in below the pipe centerline. The proper depth from Sierra documentation is shown in Figure 18.

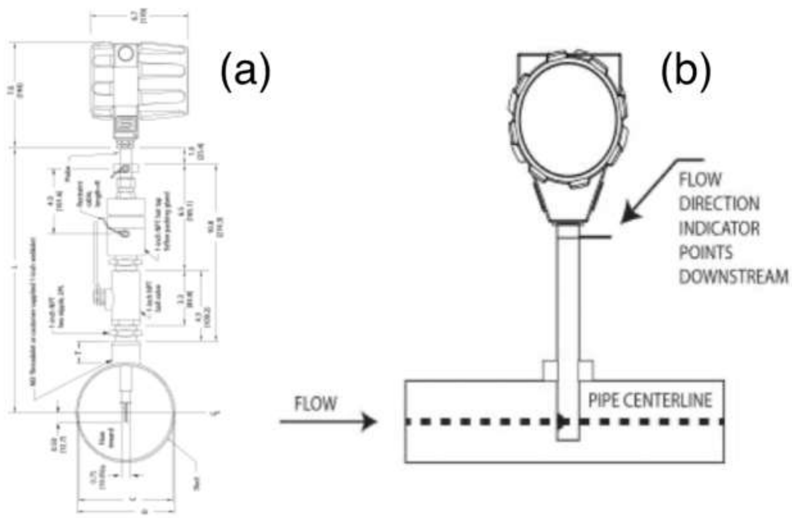

Figure 18. (a) Diagram showing proper insertion of Sierra Quadratherm 640i meter to ½ inch below pipe centerline. (b) Diagram showing flow direction of gas compared to flow direction indicator on top of meter probe.

A depth gauge was used to scribe the distance from the outer top of the compression fitting to the bottom of the pipe. The mark is then transferred to the probe of the Quadratherm, accounting for the gap required, equal to (½*D – ½) inch, where D is the inner diameter in inches.

Additionally, (Figure 18b) the meter needs to be installed so that flow is in the correct direction compared to the oriented meter probe tips. Flow needs to be downstream in the direction of the metal flow direction indicator, which protrudes at 90° to the "front" facing direction of the meter tips.

We show below tests where we purposely mis-installed the meters and compared the results to another properly installed meter.

4.3. Sierra quantification of meter uncertainty

Sierra gives the following quantification of the uncertainty in meter measurements.

For meters with actual gas calibration (in our case, calibration setting "8A"):

- +/- 0.75% of reading with additional +/- 0.5% of full scale if below 50% of full scale

For meters with air calibration, adjusted using qTherm correlations for other gases (in our case, calibration setting "8"):

- +/- 3% of full scale, regardless of flow rate

However, these are laboratory calibration stand errors, and may not represent actual field measurement errors. Field measurement errors can include other factors such as incorrect installation, which we test below.

4.4. Meter limits and full-scale flow

Sierra meters are thermal mass flow meters that use sensitive temperature probes and properties of gases to estimate the amount of gas flowing by the sensor tip. The temperature of a heated probe tip is compared to one to two other probe tip temperatures. The sensor tracks the amount of electrical energy required to maintain a constant temperature differential between the heated probe tip and the reference tip(s), which can be used to estimate the amount of gas flowing by the heated probe tip (the faster the flow past the tip and the cooler the gas, the more energy required to keep the heated tip hot).

Sensors are individually factory calibrated to a set full-scale flow level. This level of flow, measured in linear feet of gas flow per second, is the maximum level at which Sierra guarantees performance for a meter. Beyond this point, error increases, though at a rate which is unknown and not clearly reported by Sierra documentation. Therefore, in all tests below, we remove any readings above full scale. In field tests as well, flow is kept below the full scale limit.

Table 1 and Table 2 below show tabular reference material provided by Sierra showing the full scale flow for the 2016 and 2018 meters (Table 1) and the 2021 meter (Table 2). Given a particular pipe diameter, the same linear full scale flow value corresponds to a different volumetric flow rate in scf per minute. In our tests, we only inserted meters into 2, 4, and 8-inch schedule 40 steel pipe, so only those rows are relevant.

Table 1. Sierra provided full scale flow table for meters purchased in 2016 and 2018 with maximum linear full scale flow rate of 20,000 standard feet per minute.

Pipe size (schd40)	Area (ft^2)	Max velocity (stdft/min)	Max flow rate (standard cubic feet per minute)	Max SCFH	Max pressure (psig)	Pipe ID (in.)
2"	0.0233	20,000	466	27,960	300	2.067
2-1/2"	0.0332	20,000	664	39,840	300	2.469
3"	0.0513	20,000	1026	61,560	300	3.068
4"	0.0884	20,000	1768	106,080	300	4.026
6"	0.201	20,000	4020	241,200	300	6.065
8"	0.347	20,000	6940	416,400	300	7.981
8A Actual Gas Calibration0.75% of reading + 0.5% of FS from 0 to 50% of FS						
8 Calibration with Air, qTherm correlation for methane +/- 3% of Full Scale						

Table 2. Sierra provided full scale flow table for meters purchased in 2021 with maximum linear full scale flow rate of 15,837 standard feet per minute (derived from calibration to 1400 scfh with a 4" schedule 40 pipe).

Pipe size (schd40)	Area (ft^2)	Max velocity (stdft/min)	Max flow rate (standard cubic feet per minute)	Max SCFH	Max pressure (psig)	Pipe ID (in.)
2"	0.0233	15,837	369	22,140	500	2.067
2-1/2"	0.0332	15,837	526	31,548	500	2.469
3"	0.0513	15,837	812	48,747	500	3.068
4"	0.0884	15,837	1400	84,000	500	4.026
6"	0.201	15,837	3183	190,995	500	6.065
8"	0.347	15,837	5495	329,729	500	7.981
8A Actual Gas Calibration0.75% of reading + 0.5% of FS from 0 to 50% of FS						
8 Calibration with Air, qTherm correlation for methane +/- 3% of Full Scale						

4.4.1. Coriolis mass flow meter

Figure 19. Coriolis mass flow meter (left) installed in 0.5 inch pipe, connected to digital display (right)

For our smallest methane release volumes, we used a Micro Motion ELITE Coriolis meter, connected to an 0.5-inch pipe. As the name implies, these meters function based on the Coriolis force. In a Coriolis meter, the gas passes through a loop which causes the system to experience a force perpendicular to the axis of rotation. Micro Motion Coriolis meters measure the Coriolis force by inducing a vibration through the flow tube and monitoring the change in frequency due to the force.

We connected the meter to a digital display, which we connected to our Nanodac data logger. We also livestreamed the digital display via Zoom and recorded to the cloud for redundancy.

Given that internal gas pressure at the Coriolis meter was close to atmospheric pressure (~15 psi atmospheric), the manufacturer's web-based tool estimates meter accuracy at this pressure at < ±2% [6]. The web-based tool produces an accuracy plot as a function of mass flow rate of whole gas. We fit a power function to the digitized accuracy plot, estimated at $\delta_Q = 316.92 \cdot Q^{-0.969}$ where δ_Q is the uncertainty in whole gas mass flow rate (percent), and Q is the whole gas mass flow rate (standard cubic feet per hour).

The Micro Motion Coriolis documentation recommends that the meter be filled with process fluid at all times for accurate measurements. This is to ensure that it is the process fluid, and not air that are being measured. To ensure this was the case during testing, the apparatus was run for several minutes between the commencement of gas flow and any subsequent measurements were taken.

There are no straight run requirements for input our output pipelines for our Coriolis meter and it is not prone to the same potential installation error issues as insertion meters, described below.

4.5. Meter calibration

Noting that meters were out of calibration specification, Rutherford and Brandt contacted Sierra Instruments in summer 2021 to request recalibration and recertification of the meters. We were quoted calibration lead times of "at least" 6 months due to a backlog of calibration requests and the fact that the calibration equipment was offline due to parts shortages due to the COVID-19 supply chain issues.

In order to avoid this delay, which was infeasible given other scheduling constraints, a new and nearly identical model meter ("2021 meter") was purchased with factory calibration performed. This new meter could then be compared to other meters by placing them in series in the same gas flow path such that all gas flowing past the first meter then flowed past the second meter. The diagram of this serial meter setup is shown in Figure 20, with the apparatus beyond Meter A described in detail in the "Metering and release trailer" section describing the Arizona setup.

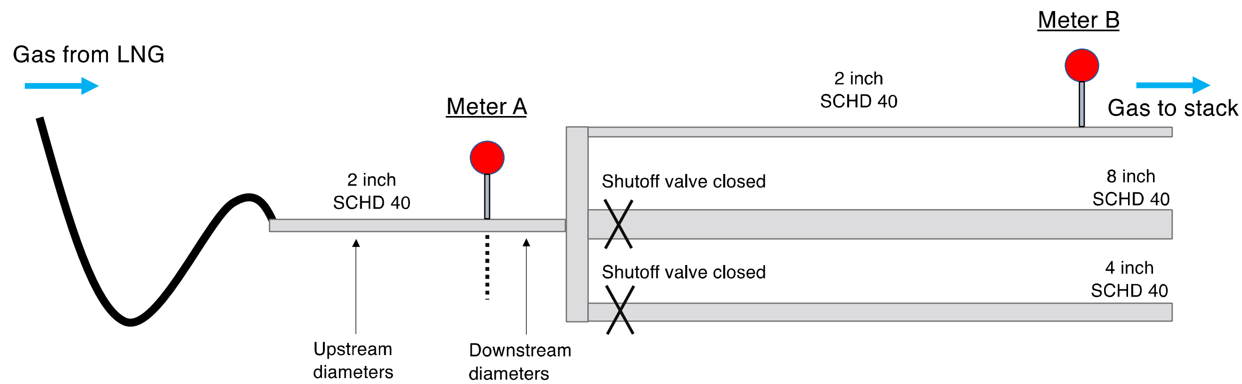

Figure 20. Serial meter setup with meters A and B in series with all gas flow past meter A then passing meter B. Shutoff valves on other pipes were closed and tested for integrity of closure using FLIR GasFind 320 camera. In one test, Meter B was installed into the 4 inch pipe.

Figure 21. The serial meter setup in practice in the field (without meters installed).

On October 29th-31st of 2021, a series of 18 meter comparison tests were performed. These were performed to compare the older meters (2016 and 2018 meters) to the new factory calibrated meter (2021 meter). We also sought to understand the kinds of errors that would arise from mal-installation of the meters. The location and comparison unit of the meters were switched between each test. The tests lasted for 10 to 20 minutes in general, stepping through volumes between 0 scfh and the maximum full-scale flow of each meter. In each case, we construct the time series of the two meter readings, as well as the time series of the mean of the two meters. In all discussion to follow, we assume that the mean of the measurements from the two meters is the best estimate of the actual flow rate.

The data processing path is as follows:

1. Data are imported into MATLAB for each test separately from meter software generated CSV files
2. Data are cleaned of rows containing:
    a. no flow rate entry (i.e., blank or NaN);
    b. negative flow meter reading (small values typically when near zero flow);

c. flow rate in excess of maximum full-scale flow for either meter in series;
d. flow rate below 3% of meter full scale
e. the first 60 seconds and last 60 seconds of each test to remove erratic behavior at start and end of flow
3. The resulting test contains two time series of flow rates, one for each meter.

Tests of general meter functioning and error are listed below in Table 3. Tests of meter mal-installation are listed below in Table 4.

Table 3. Meter intercomparison tests with no purposeful mis-installation

Test number	Meter location			Evidence of systematic error?	Meter age reading high	Meter location reading high
	Small/Front	Large/Rear 2 in	Large/Rear 4 in			
1	2018	2016		Y	Old - 2016	Large/Rear
2	2021	2016				
3	2021	2016				
4	2021	2018		Y	New - 2021	Small/Front
6	2018	2021				
7	2016	2021				
8	2016		2021			
11	2016	2021		Y	Old - 2016	Small/Front
14	2018	2021				
16	2016	2021		Y	Old - 2016	Small/Front
17	2021	2016		Y	Old - 2016	Large/Rear
18	2021	2018		Y	New - 2021	Small/New

Table 4. Meter intercomparison tests with purposeful mis-installation of one of the meters.

Test order number	Small test rig (front)	Large test rig (back)	Installation error tested
4	2021	2018	Control for depth of insertion, both meters installed at mark
5	2021	2018	Old meter installed incorrectly, raised 0.5mm from mark
9	2016	2021	Old meter rotated 180 deg
10	2016	2021	Old meter rotated 90 deg CCW
12	2018	2021	Old meter rotated 180 deg
13	2018	2021	Old meter rotated 90 deg CCW
15	2018	2021	Old meter rotated 270 deg CCW

4.6. Tests of meter intercomparison – No mis-installation

The time series of the meter inter-comparison tests are shown in Figure 22 and Figure 24. In Figure 22 we have included tests where there is no apparent consistent divergence between meters, or in which the divergence is very small (e.g., sub-figure (a)). The colored bar at the top of each time series shows the color of the meter that reads higher in that time step (on per-second basis). We see variability in which meter reads higher over the course of 10s of seconds to minutes. We do not see significant second-by-second noise, which would appear as rapidly fluctuating color shifts in the top bars. Thus, it appears that meter noise occurs over the scale of multiple seconds to minutes.

We can see in these cases, average divergence between the two meters tends to be quite small. For these tests, the mean and standard deviation of the two meters, normalized by the mean reading (best estimate) are shown in Table 5. Thus, on this scale, two meters that always agreed completely would have mean of 1 (row 1 of Table 5) and standard deviation of 0 (row 3 of Table 5). Thus, we can see in these cases with no apparent systematic error, the 1 SD noise in the measurements of a single meter is 1-2% compared to the average of the two meters.

Note that this noise, while largely cancelling out over the course of a 30 minute test in these 6 tests, can persist over scales of multiple minutes. Therefore, we must include an error term for noise that can persist over the course of a (for example) 2 or 5 minute release period.

Table 5. Summary statistics for tests were there is little or no observed systematic bias between meters upon visual inspection

	Test 2	Test 3	Test 6	Test 7	Test 8	Test 14
Mean error (front /average)	0.9866	0.9982	1.0043	1.0017	1.0034	0.9990
% bias rel. to mean	1.34%	0.18%	0.43%	0.17%	0.34%	0.1%
SD of error (front/average)	0.0143	0.0205	0.0120	0.0128	0.0175	0.0155
% noise (1 SD) rel. to mean	1.43%	2.05%	1.20%	1.28%	1.75%	1.55%

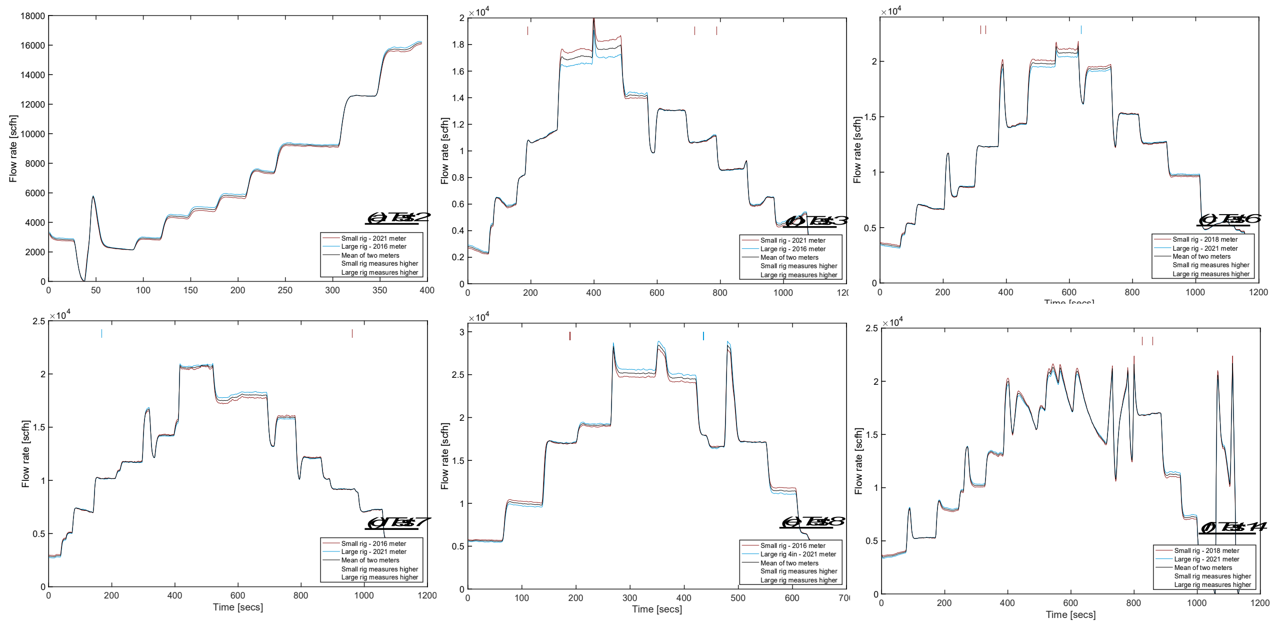

Figure 22. Time series plots for tests with no significant and consistent bias or divergence between meter measurements.

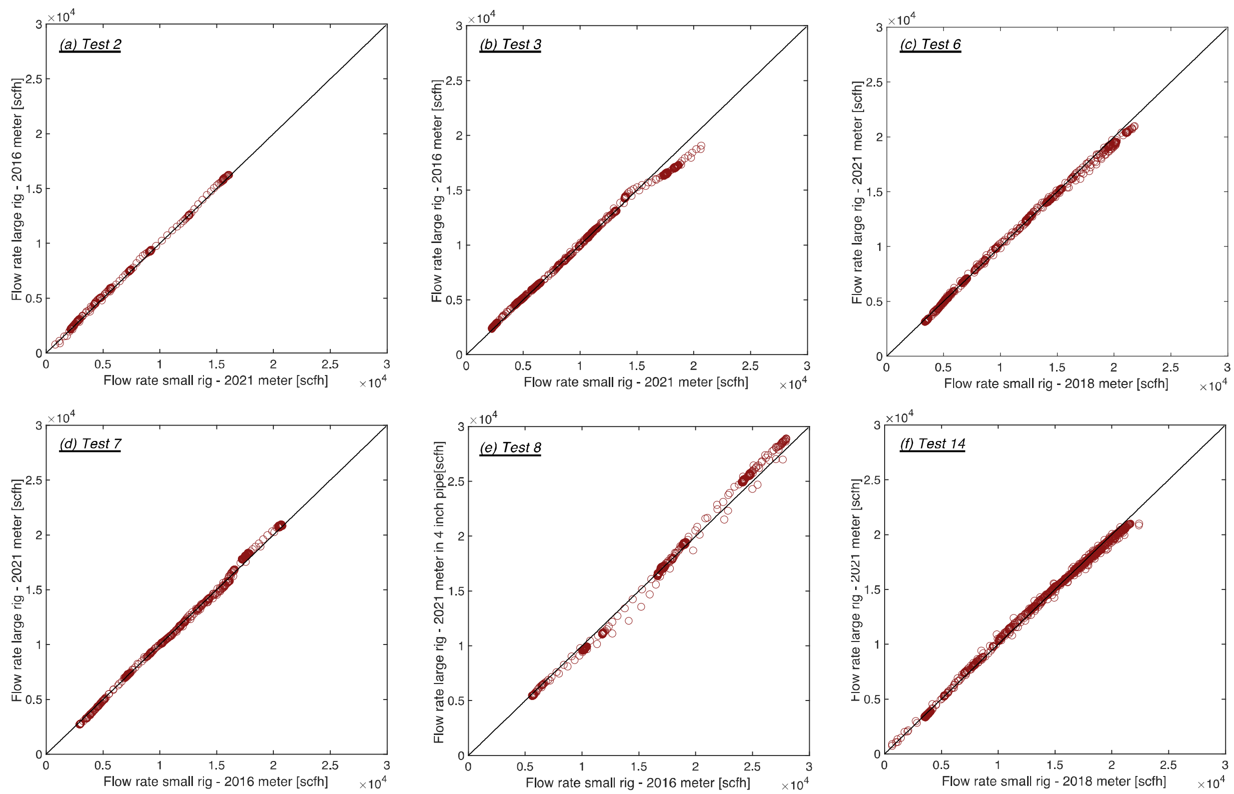

Figure 23. Parity charts showing level of agreements between meters in various tests. These cases show little consistent divergence between meter readings and are taken to be representative of the amount of irreducible noise present in measurements when no installation issues arise.

Some of the tests appear to show systematic divergence between the two meter readings. For example, one meter may read higher than the other across the entire ~20 minute test. If the meters were installed correctly with no systematic error, we would not expect this to be the case. A total of 6 of the tests were classified by visual inspection as having some systematic error. See Figure 24. The resulting summary statistics are shown in Table 6. We can see that relative to the average of the two meters, one of the meters can be high or low by up to ~6% in cases where we attempted to install the meters correctly.

The SD rows in Table 6 show the SD remaining after the bias is adjusted for by dividing the front meter by the mean error across all of the observations. This averages out the overall bias in the measurement and leaves noise. After doing this, we see that the 1 SD noise in the tests is similar to that seen above in the cases where there was no systematic error. Thus, cases with a systematic divergence between the two meters do not seem to exhibit increased random noise compared to the cases above without obvious systematic error.

Table 6. Summary statistics for tests were there is systematic bias between meters upon visual inspection

	Test 1	Test 4	Test 11	Test 16	Test 17	Test 18
N valid measurements	2342	1088	863	781	886	1435
Mean error (front /average)	0.9430	1.0273	1.0377	1.0308	0.9726	1.0339
% bias rel. to mean	5.70%	2.73%	3.77%	3.08%	2.74%	3.39%
SD of error after bias correction (front /average)	0.0385	0.0121	0.0120	0.0175	0.0203	0.0231
% noise (1 SD) rel. to mean	3.85%	1.21%	1.20%	1.75%	2.03%	2.31%

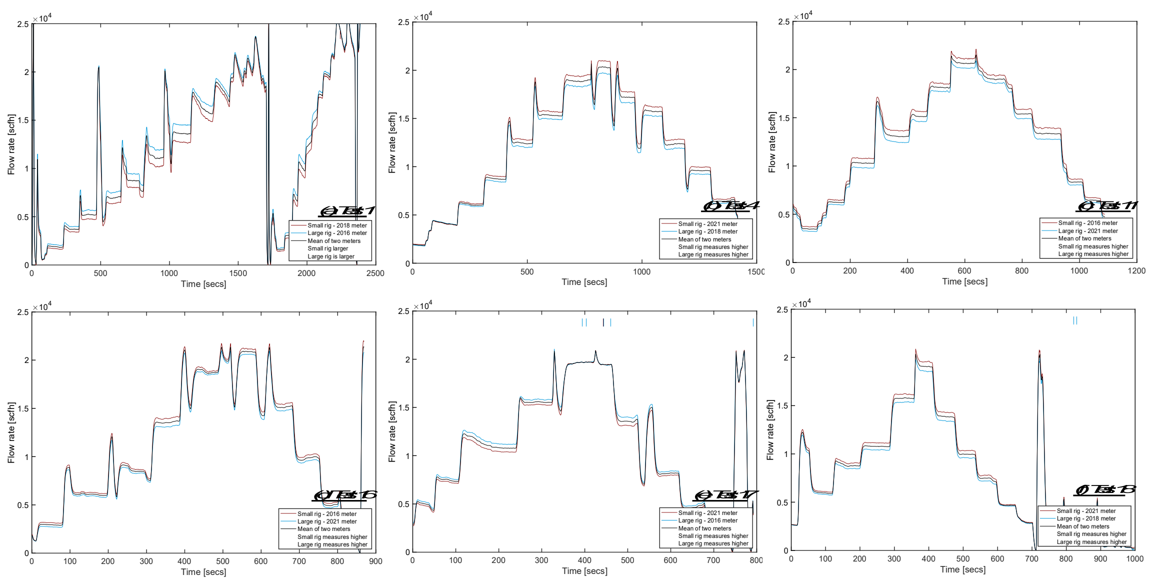

Figure 24. Time series measurements for tests where there was consistent bias in measurements between meters. Bias is evidenced by consistent color bar at top of each sub-figure, showing that one meter is very consistently higher than the other.

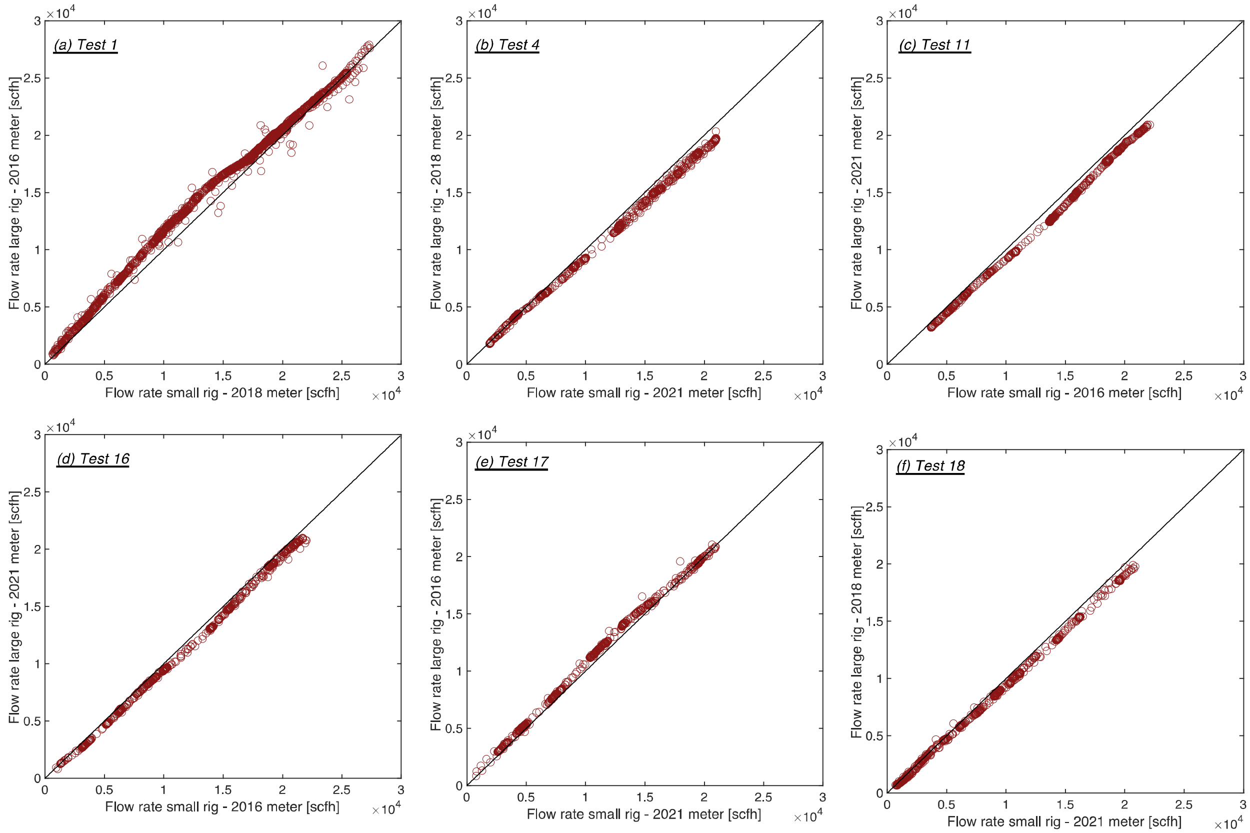

Figure 25. Parity charts showing agreement between meters in tests where there was consistent divergence or bias between meter readings.

From the results above, we can see that even in cases where installation was performed carefully and without intention of mis-installation, a mean difference of up to 6% from the average of two meters was observed.

Examples of noise (and error in excess of noise) for two cases are shown in Figure 26. Figure 26a shows a case (Test 4) where we suspect systematic error and Figure 26b shows a case (Test 6) where we do not suspect significant systematic error. We see that the Sierra-supplied error envelopes encompass each other in the majority of time steps in the case without suspected systematic error. Error bands are wider at the start and end of the test due to the way in which Sierra error envelopes are defined.

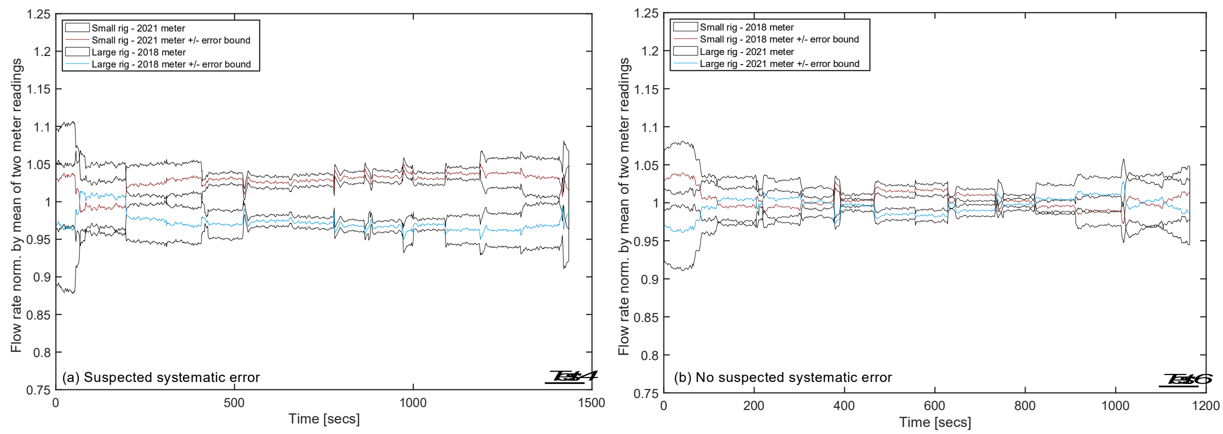

Figure 26. Relative divergence from mean flow (mean flow = 1) for both meters during two tests, with Sierra-estimated error envelopes included as light shaded regions. Examples show tests where we suspect systematic error (a, Test 4), and where no systematic error is suspected (b, Test 6).

4.7. Tests of meter mis-installation

In order to better understand the reasons for divergence between meters, a number of tests were performed where the meters were purposely mis-installed. As shown above in Table **4**, 6 tests were performed where the meter was purposely installed incorrectly. In Test 5, immediately following Test 4, the older of the two meters (2018 meter on large rig) was raised 5 mm. In Tests 9 and 10, the old meter (2016) was rotated 180 degrees and 90 degrees counter-clockwise (CCW) from the direction of correct installation. In Tests 12 and 13 the 2018 meter was rotated similarly. Finally, in Test 15, the 2018 meter was rotated 270 degrees CCW.

The results of the testing are shown in below in Figure 27 and Figure 28. In Figure 27 we see that the test 4 results showed consistent divergence between the meter readings, evidence of a systematic source of error. The older meter was adjusted up 5 mm, then test 5 was run. We can then see that the divergence between the meter readings essentially disappears. The mean divergence between each meter and the average of the two meter readings is 3% over the entire range in test 4. It is larger at higher flow rates, reaching 4.5% at the maximum flow rates. Thus, mis-installation of meters in the vertical direction by 5 mm can result in divergence of ~5%.

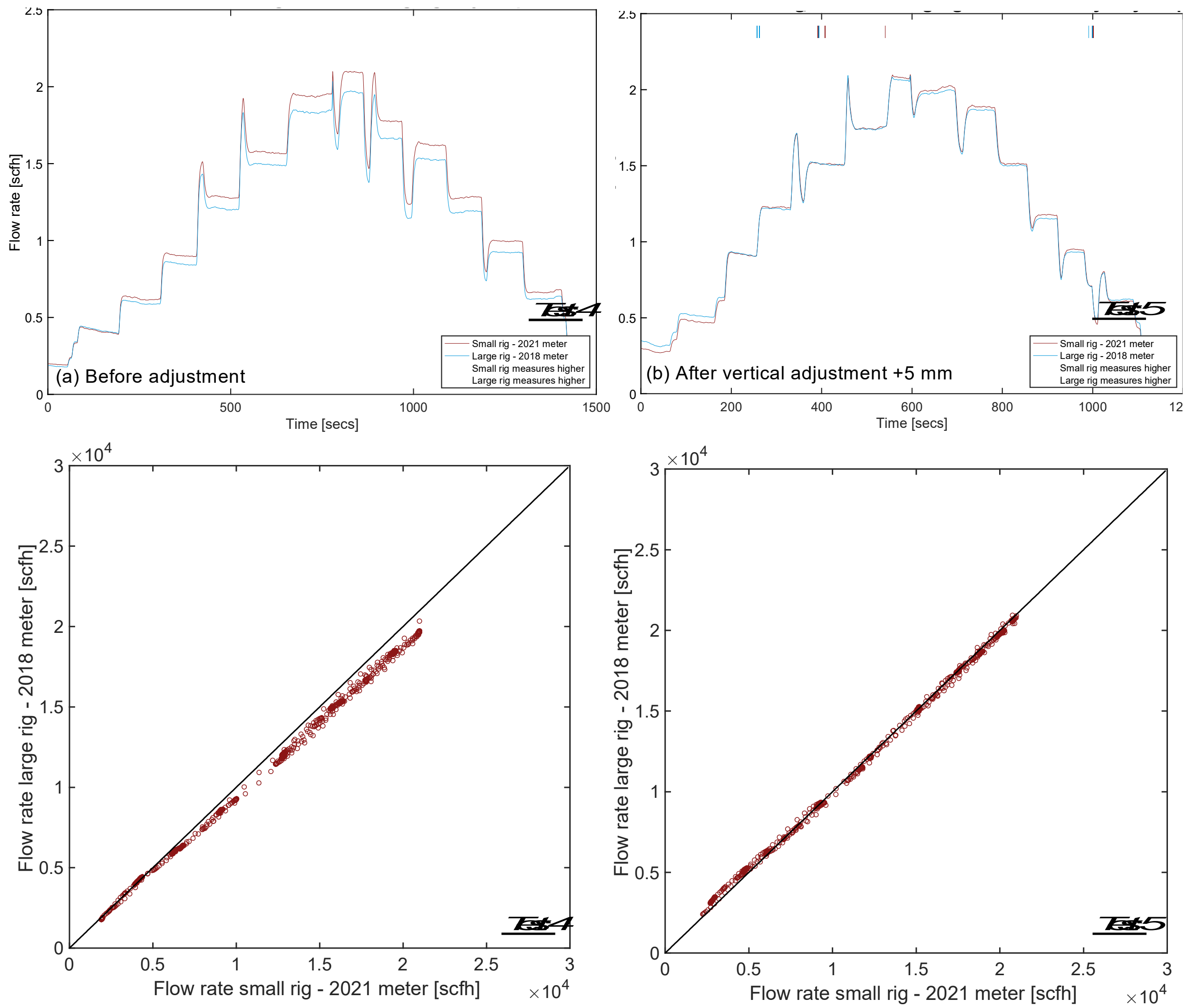

Figure 27. Effects of raising the meter by +5mm from test 4 position (left) to test 5 position (right). Bias present in test 4 is removed by raising the meter in test 5.

In Figure 28 we see the effects of rotating a meter by 90 degrees and 180 degrees in Tests 13 and 12 respectively (L and R side of Figure 28). A 90 degree rotation results in errors that grow with flow rate, reaching a maximum divergence between the two meters of 20%. A 180 degree rotation can result in errors as large as 40% at the maximum flow rates.

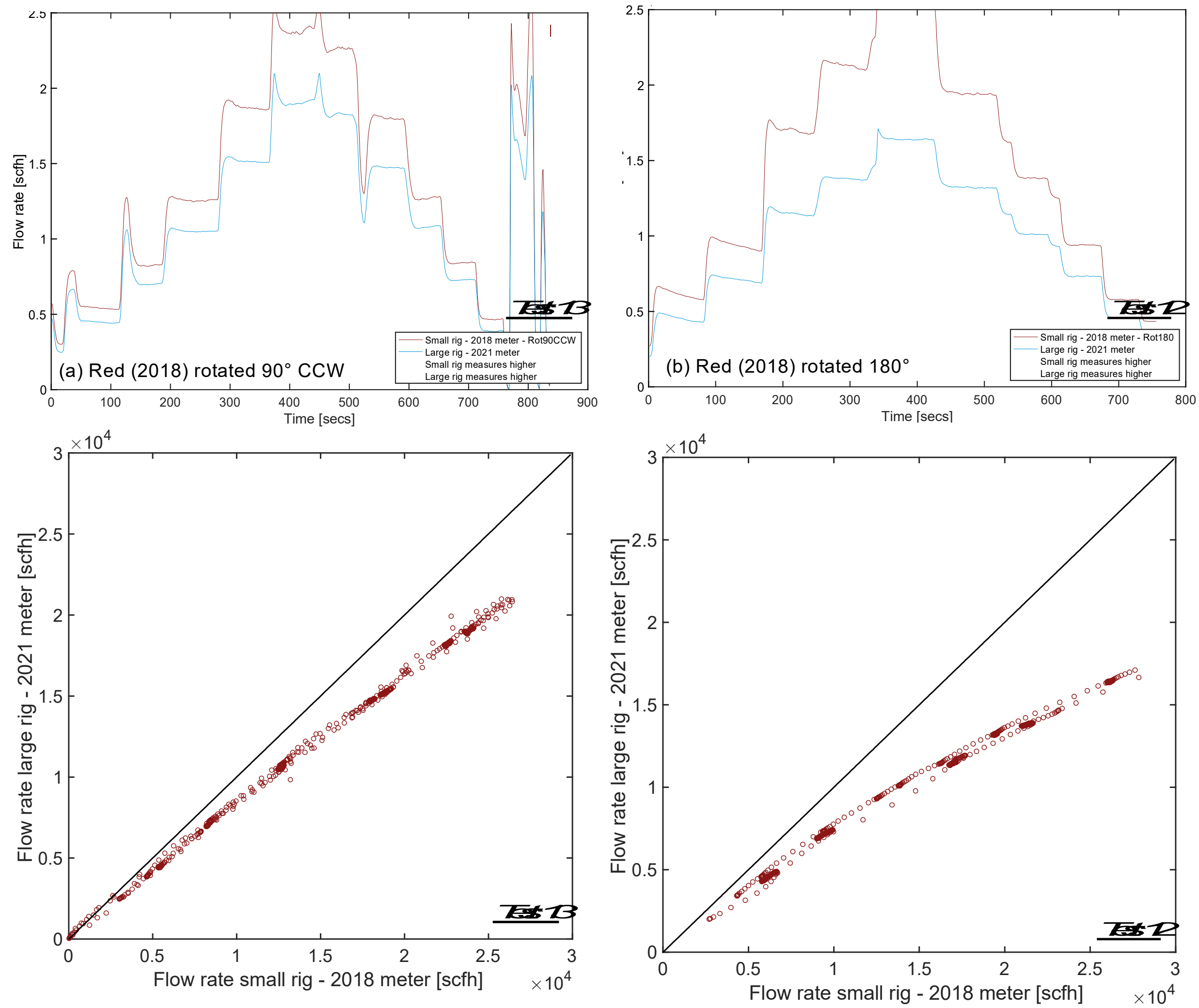

Figure 28. Effects of rotating meters by 90 degrees (test 13, left) and 180 degrees (test 12, right).

4.8. Accounting for error in the measurements

Our aim is to calculate actual emissions in kg CH_4 per hour from our metering system. What we measure (imperfectly) is the flow rate of whole natural gas in standard cubic feet per hour (scfh) past the meters in our system. In order convert scfh of whole gas to kg CH4 per hour, and to simultaneously model the uncertainty in our measurements, we apply the following Monte Carlo resampling approach to estimate the error distributions. All of these operations are applied to the average flow rate computed by averaging 1 Hz or 10 sec interval data over the relevant time period of flow for a given methane-sensing measurement (90 seconds by default).

4.8.1. Step 1: Adjust for possible systematic bias

First, we adjust for possible systematic bias. The 12 experiments listed in Table 3 above were experiments in which the meters were installed without intentional mal-installation. We take these results from these tests as indicative of the possible systematic errors arising from installation differences, mal installation, or inconsistencies. These 12 tests therefore serve as data on the likely systematic errors that might arise in regular installation (i.e., on the days when we were not comparing the flow through two meters). In each test, we assume that for each 1 Hz measurement that the mean of the two meter readings is our best estimate of the true flow rate.

Taking the mean flow rate of the front and back meter in each of the 12 experiments, and comparing those meter averages to the average of the mean of the two meters, we obtain a database of 24 divergences from the expected mean of the two meters (2 – front and back – for each of 12 Tests). These systematic divergences are partially listed above in Table 5 and Table 6, and are plotted below in Figure 29.

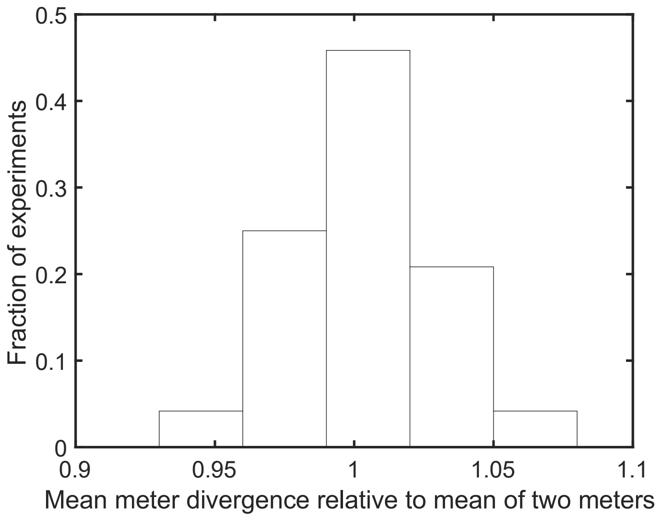

Figure 29. Mean meter divergence for front and back meters relative to mean of average of two meters in each of 12 tests.

We sample - uniform with replacement - from the list of systematic divergences illustrated in Figure 29. The systematic bias drawn is almost always between 0.95 and 1.05, with a small chance of larger divergence. This systematic bias is applied as a multiplier to the whole gas flow rate measured by the meter. This error term represents consistent bias over an entire testing period.

4.8.2. <u>Step 2: Adjust for meter noise</u>

We see in the above plots – even in cases not suspected of systematic error –periods of high or low measurement in line with Sierra error estimates can last multiple minutes. For example, see Figure 27 for divergence from the mean for Test 6. Overall, the tabular results show us that the mean of the two meters in Test 6 diverged by 0.43% averaged over the whole test. But we see excursions of up to 1-2% from the average that last on order 10s to 100s of seconds. Because we see in Figure 27 that these errors are of the scale of the Sierra-suggested noise in the meters, we model these non-systematic biases using the Sierra error estimation method, described on pp. 11-14 of Sierra meter documentation.

Note that the 2016 meter is air-calibrated, and methane is added as a computed gas calibration option ("8" calibration option for methane). The reported error for option 8 calibration is +/- 3% of full scale for a particular reading.

For the 2018 and 2021 meters, actual gas calibration was performed at the factory with methane. This is listed as calibration option "8A". Actual gas calibration for methane results in error that is +/- 0.75% of the reading at above 50% of full scale, and 0.75% of reading + 0.5% of % full scale at below 50% of full scale.

While it is not described clearly in the Sierra documentation, we assume these error bounds are 95% confidence interval, and errors are assumed to be Gaussian in nature with a 95% CI representing 1.96 SD uncertainty.

This allows us to sample a noise term from this distribution, depending on the meter vintage, size of pipe in which it is installed (for full scale flow correction) and the flow rate. This noise term is applied as a random adder to the value derived from output of Step 1, (i.e., after systematic bias adjustment). This is justified because we find that when we correct for systematic bias we still retain noise that is of similar magnitude to the cases without systematic bias (as discussed above).

4.8.3. Step 3: Gas composition

The last step is to adjust for the gas composition and gas composition variability. Even if there were no variability or uncertainty in gas composition, we would still require a conversion factor to go from scfh of whole gas to kg per h CH_4. Gas composition is collected at intervals by the gas supplier. Gas composition is not collected by the supplier for each cargo of gas sold, so we do not have readings for each tank of gas filled at the CNG/LNG fueling station.

In Midland TX, our fuel supplier supplied the most recent complete month of daily gas composition readings (June 2021) performed before our releases. Per personal communication with CNG station operators, gas composition analysis is not performed daily at all times of the year, but during certain intervals to satisfy reporting requirements. These gas composition readings are entered as discrete options, we sample using a discrete uniform distribution with replacement. The resulting distribution has mean of 85.89 mol% CH_4, with SD of 1.23 mol% CH_4. The 5th percentile observation is 84.66 mol% and the 95%ile is 88.23 mol% CH_4.

In Ehrenberg AZ a weekly compositional analysis was performed by the gas supplier and obtained via request. The weekly compositional fractions of CH_4 are 96.27%, 95.22%, and 96.13% (all mol% CH_4). LNG composition is controlled more carefully and it contains a higher fraction of CH_4. This is due to problems with freezing if contaminants are present or higher hydrocarbons are present in large quantities. Because these compositions are taken once per week and do not necessarily correspond to our cargoes, we again sample from these provided distributions using a discrete uniform distribution with replacement.

Using a selected molar composition from above -- depending on the location --

the scfh of whole gas is lastly converted to scfh of CH_4. Sierra documentation suggests that standard conditions (i.e., the "s" in scfh reported on meter readout) is 21.1 C and 1 atmosphere pressure [7]. This temperature and pressure is used with ideal gas relations to derive moles per scf. The value of moles per scf is equal to 1.1728 moles per scf.

Example distributions are shown below in Figure 30. In case 1 (left, a), whole gas metered flow rate is 10,000 scfh, and location is AZ. The mean estimated CH_4 release rate is 9623 scfh, with and a mean-normalized SD of 0.0287 or 2.87% of the mean flow rate. In case 2 (right, b), the whole gas release rate is 2000 scfh, while the mean estimated CH_4 release rate is 1717 scfh, with a mean-normalized SD of 4.93% of the mean flow rate. Uncertainty is larger in case 2 because of the lower flow rate (smaller fraction of full-scale flow) and the location being the location with wider gas composition uncertainty. Use of the meter with less accurate metering (2016 meter) also results in a wider distribution.

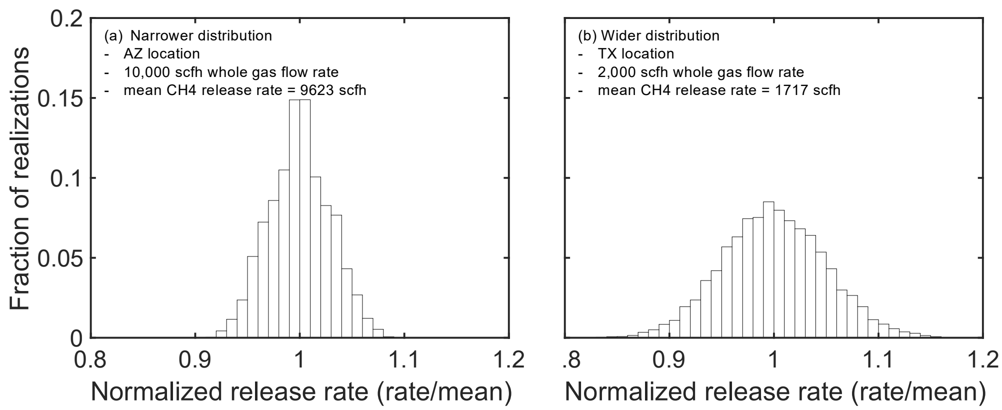

Figure 30. Example uncertainty distributions for two cases. Uncertainty is larger in case b because of the lower flow rate (smaller fraction of full-scale flow) and the location with wider gas composition uncertainty.

4.8.4. Step 4: Add additional noise to hand-recorded data

Finally we add an additional bias and noise term to hand recorded data. Because the hand-recorded data is at a much lower resolution compared to the Nanodac-recorded data or the OCR-recorded data, the rolling averages will underrepresent variance. We add additional bias and variance terms assuming that the bias and noise of the full data sample (all days sampled by the specific technology) is representative of what was missed while data was hand recorded.

For each operator, we take the full dataframe and for each averaging period T (30, 60, 90, 300, 600, 900 seconds), we calculate $\overline{Q_T}/Q$ (Where $\overline{Q_T}$ is the rolling average for averaging period T, and Q is the instantaneous recorded measurement) and the associated mean and standard deviation. The mean and standard deviation terms are added as additional bias and noise terms in the uncertainty quantification algorithm.

5. Data Processing Algorithm

The operator survey summary sheets and Stanford logged data were loaded into a Python processing script. The primary objectives of the script are as follows:

(i) Loading various data sets
(ii) Merging data sets
(iii) Data classification and data exclusion
(iv) Data uncertainty

This script was used to process data for aircraft mounted sensors, satellites, and stationary ground sensors.

5.1. Loading release data sets

First, the data processing algorithm (summarized in Figure 31) loads (i) the filled, standardized reporting sheets for all operators, (ii) Stanford release time series (including Nanodac-logged data, iPhone video digitized via Optical Character Recognition, and handwritten field data) for both the Quadratherm and Coriolis meters, and (iii) wind data.

Given that Stanford utilized multiple data logging streams for release data, the data processing algorithm required a data prioritization structure for the final analysis. Data logged with the Nanodac recorder are used first if it is available. If the Nanodac was not used (the Nanodac was installed partway through the Arizona campaign and Stanford had not received the ordered Nanodac recorder in time for the Texas campaign), data digitized from the Zoom video recordings using Google's Optical Character Recognition service are used [9]. If video is not available then timestamped data recorded in the field are used.

There are three instances where timestamped field notes are used. The Optical Character Recognition service is unable to read the data on July 31 15:22 – 16:05, the video feed stopped recording on October 19 20:20 – 20:34, and on November 4 19:28 – 19:57, the Nanodac data logger appears to have frozen (based on comparisons of the hand-recorded data from the Zoom video feed). In each of these cases the hand recorded data (at the instant the operator aircraft flew overhead) of the video feed was used.

Data was logged at different frequencies (Nanodac = secondly, Texas optical character recognition = 10 secondly (due to low quality caused by sun glare), Arizona optical character recognition = secondly, real-time field data recorded at revisit intervals. To consolidate at a consistent time frequency, all data streams are joined with a secondly data frame and backfilled to form a continuous release time series. Zero-release timestamps are imported to apply zeros and verify that backfilling did not overwrite periods of zero release. Quadratherm data is imported in units of standard cubic feet per hour (scfh) whole gas and Coriolis data is imported in units of grams per second (gps) whole gas. Data from the two meters is consolidated into a single column by converting Coriolis readings to standard cubic feet per hour of whole gas.

Given the limited information Stanford has regarding each operator's (generally proprietary) quantification algorithms -- including what fraction of the plume image is used -- multiple rolling averages are calculated. Results are presented for 30, 60, and 90 second windows for airplane sensors, and 300, 600, and 900 seconds for satellite sensors.

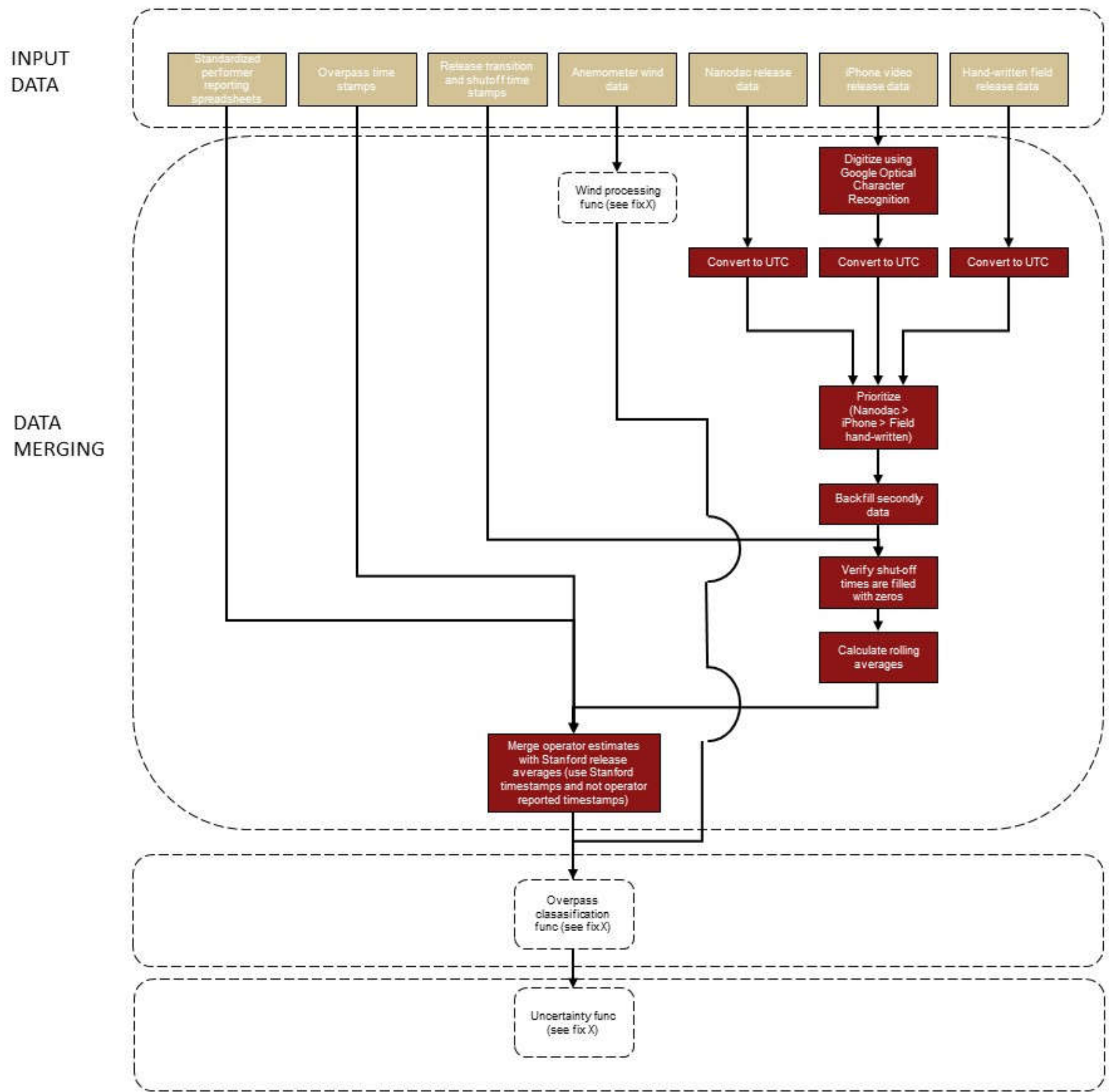

Figure 31: Flow chart summary of controlled release data processing algorithm

5.2. Loading wind data sets

Data outputs from the Gill Windview software [10] are processed for use in the data processing algorithm. Gill WindView is programmed to export the data log at 10 minute intervals. The 10 minute segments of data are compiled to produce a single CSV file for each day. All data recorded on the anemometer is in Pacific Standard Time (PST). The data processing algorithm converts time stamps from PST to Coordinated Universal Time (UTC). The laptop computer logging ultrasonic data was found to have a small time offset compared to satellite time. This offset was documented periodically and adjusted in the data processing algorithm. The time offset was small (3 seconds) during the Midland, Texas campaign, likely because the laptop was briefly connected to the internet. Given that the laptop was not connected to the internet between the Texas and Arizona campaigns, or at any point during the Arizona campaign, the time offset grew larger during Arizona testing (59-71 seconds, Figure 32).

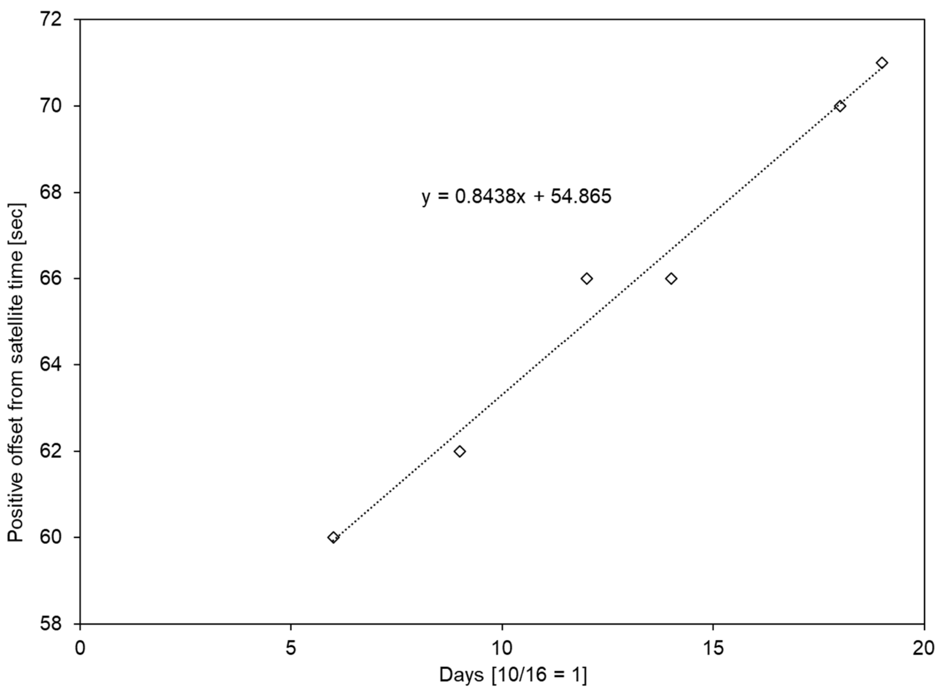

Figure 32: Positive offset (seconds) between time as reported by the wind speed logging computer and real time as reported by the researcher's cell phones. Time offset was documented by periodically taking timestamped photos of the computer clock on screen.

5.3. Merging data sets

The merged data table is created by joining by timestamp the Stanford secondly data table of release volumes with the operator data table of estimated release volumes. The final data table contains one row for every pass that the operator made over the Stanford release site. This includes both periods where Stanford was releasing as well as periods where Stanford shut off the gas to test for false positives.

Although operators report time stamps of acquisitions, in the case of some operators these are rough approximations. For consistency, we replace the operator reported timestamps with Stanford timestamps. Stanford timestamps were recorded by documenting when the operator aircraft was (visually estimated to be) directly overhead of the release stacks. A combined data table is generated by matching timestamps in the secondly Stanford release dataset with the standardized operator data reporting sheets.

5.4. Data classification and data exclusion.

In the data classification and exclusion step, we apply criteria to each row of the matched data frame to determine if and in what way, on both the operator and Stanford end, each acquisition was successful or unsuccessful (i.e., did the operator see the plume or not see the plume, did the operator incorrectly identify a blank release, or on the Stanford end, was there insufficient time for the plume to develop or not). Detections are classified as: NE: not established, FN: false negative, FP: false positive, TN: true negative, NS: not steady, or TP: true positive (Table 7).

Data exclusion criteria are used to identify cases when the logged Stanford release volumes might be unrepresentative of the plume formed over the release stack at a particular instance. Such a case could be due insufficient plume development or an unsteady plume (classified as NE: not established and NS: not steady, respectively). If a plume is classified as NE or NS, it is excluded from the operator results. The data exclusion algorithm is summarized in Figure 33.

An established plume is one that has had sufficient transport time to be fully established, where fully established is defined here to be a length of 150 m at the target release rate (Carbon Mapper uses 150 m of plume for quantification, Duren et al. [11], and this was the recommended establishment criteria for Bridger).Thus, an established plume meets the following criteria:

$$L = \int_{t_1}^{t_2} v\mathrm{dt} > 150 \text{ m}$$

Where L is the plume length (m), t_1 is the time at which the current release level commenced, t_2 is the time of the acquisition, and v is the sonic measured wind speed.

To check if the plume is steady, we calculate the fractional difference between the instantaneous metered reading and the 60 second rolling averaged metered reading, and classify as NS if the fractional difference is greater than 0.1.

$$1 - \left|\frac{\overline{Q_{60}}}{Q_{inst}}\right| > 10\%$$

If both of these tests are passed – that is, the plume is developed and steady -- the release is considered valid from the Stanford perspective. For each release considered valid from the Stanford perspective, the results are classified as given below in Table 7, depending on what the operator reports.

The QC codes for each operator are defined as given in Table 7.

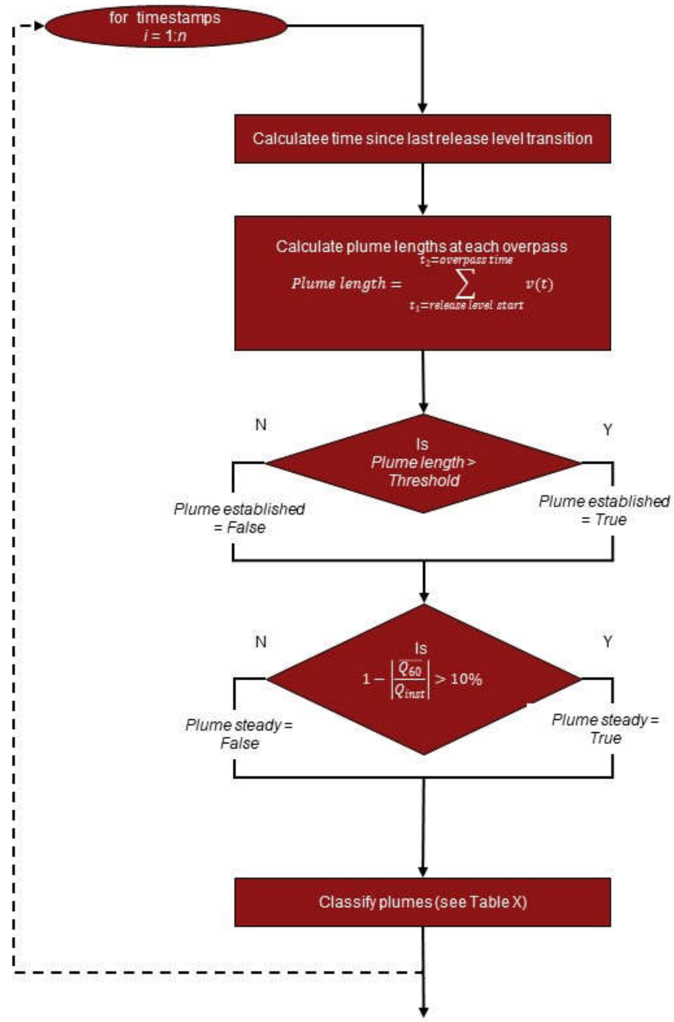

Figure 33: Flow chart summary of the data exclusion algorithm

Table 7: Data classification logic for airplane sensing operators (not including data exclusion criteria, described separately). Data classification is based on the operator reported emission rate (Q_{op}, or "FacilityEmissionRate" column in the standardized spreadsheet), the Stanford averaged release rate ($Q_{release}$), and operator reported Quality Control (QC, if available).

	Carbon Mapper	Bridger	GHGSat-AV[1]
True Positive (TP)	No other classification	No other classification	No other classification
True Negative (TN)	Q_{op} = NA $Q_{release} = 0$	Q_{op} = NA $Q_{release} = 0$	Q_{op} = NA $Q_{release} = 0$
False Positive (FP)	QC = 1 $Q_{release} = 0$	$Q_{op} \neq$ NA $Q_{release} = 0$	QC = 1 $Q_{release} = 0$
False Negative (FN)	QC = 2 $Q_{release} > 0$	Q_{op} = NA $Q_{release} > 0$	QC = 2 $Q_{release} > 0$
Error (ER)	QC = 0	No errors reported	QC = 0

[1]A separate QC column was created for GHGSat. QC = 0 assigned if GHGSat-AV added a comment describing a failed retrieval. QC = 2 if "FacilityEmissionRate" was left blank (no emission detected. QC = 1 for positive detections.

6. References

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7. Supplementary Figures

Therm / Calibration Certificate

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CERTIFICATE NUMBER 6869533284

PAGE 1 OF 1

Applicant/Customer	Name	MANCO		
	Sales Order	R158709		
	Purchase Order	WAIVED		
Instrument	Model	640i-VTP-1-L13-M1-E2-P3-V6-DD-MP3-0-2-8-10		
	Serial number	162928		
	Tag #:	N/A		
	Input Power	100-240 VAC		
	Factory Flow Full Scale	1788.0	units	SCFM
	Temperature Full Scale	212.0	units	°F
	Pressure xdcr Full Scale	300.00	units	PSI a.
	Dial-A-Pipe Set up	4.026"		
	Accuracy DUT (+/-)	0.75% Rdg > 50% F/S	0.75% Rdg + 0.5% F/S < 50% F/S	
Calibration method	Calibration Station/Cal Due Date	Gas Loop Asset # 0709	June 25, 2015	
	Calibration Procedure	7311 Rev. E		
	Software release	Gas Loop Calibration System, llobelvb Rev. 00.05.24		
	Flow Repeatability	+/- 0.15% of full scale		
	DMM Asset / Cal Due Date	1333	November 7, 2015	
	Temp. Asset / Cal Due date	800	June 25, 2015	
	Date of calibration	June 8, 2015		
Calibration data	Ambient pressure	29.93	In Hg g.	
	Ambient temperature	68.30	°F	
	Gas	Air		
	Calibration gas	Air		
	Reference temperature	70.0	°F	
	Reference pressure	1	ATM	
	Calibration pressure	14.70	PSI a.	
	Calibration temperature	70.00	°F	
	Dial-A-Gas Accuracy >50% FS (0.5% <50% FS)	CO2 ± 3% Full Scale, CH4 ± 3% Full scale, N2 ± 3% Full Scale		
	Other RFQ - SOR	Q-Mix capable		

Calibration results

Flow					
Output	Indicated Flow	Actual Flow	Difference	Difference	% Actual
4-20 mA	SCFM	SCFM	Allowable	Actual	Error
4.000	0.001	0.000	8.84008	0.00000	0.0000
5.972	217.939	217.519	10.47139	0.41990	0.1930
9.914	653.450	652.558	4.89418	0.89252	0.1368
13.850	1088.414	1087.596	8.15697	0.81770	0.0752
17.775	1522.160	1522.635	11.41976	-0.47515	-0.0312

Temperature Accuracy +/- 1.8 °F					
Output	Indicated Temp.	Actual Temp.	Difference	Difference	% Actual
4-20 mA	°F	°F	Allowable	Actual	Error
7.544	71.870	72.4000	1.8000	-0.5300	-0.7320

Pressure Accuracy +/- 1% of XDR Full Scale					
Output	Indicated Press	Actual Pressure	Difference	Difference	% Actual
4-20 mA	PSI a.	PSI a.	Allowable	Actual	Error
5.157	21.6938	21.900	3.0000	-0.2062	-0.9418

Traceability Calibration of Sierra products is performed with equipment containing components which are tested and calibrated in accordance with ANSI/NCSL Z540 and/or ISO 17025 and are traceable to NIST. The results of this report relate only to the item calibrated or tested.

Calibration technician ____________ Q.C.Technician ____________

Warranty Registration To assure warranty service, register this instrument at www.sierrainstruments.com/register

This calibration certificate shall not be reproduced, except in full, without the written approval of Sierra Instruments, Inc.

SI Form P. Sierra 0001 Rev. C

Figure 34: Calibration certificate for Sierra Instruments Quadratherm 640i meter (serial number 162928)

Therm / **Calibration Certificate**

5 Harris Court, Building L • Monterey, California • (800) 866-0200 • (831) 373-0200 • Fax (831) 373-4402 • www.sierrainstruments.com

CERTIFICATE NUMBER 9452241995

PAGE 1 OF 1

Applicant/Customer	Name	RAWHIDE LEASING
	Sales Order	183411
	Purchase Order	042318-WTG
Instrument	Model	640i-VT-1-L13-M1-E2-P3-V4-OD-0-8A-8-10
	Serial number	218645
	Tag #:	N/A
	Input Power	100-240 VAC
	Factory Flow Full Scale	27960.0 units SCFH
	Temperature Full Scale	212.0 units °F
	Pressure xdcr Full Scale	N/A units N/A
	Dial-A-Pipe Set up	2.067"
	Accuracy DUT (+/-)	0.75% Rdg > 50% F/S 0.75% Rdg + 0.5% F/S < 50% F/S
Calibration method	Calibration Station/Cal Due Date	Gas Loop Asset # 0709 June 25, 2018
	Calibration Procedure	MPG-641
	Software release	Gas Loop Calibration System, Robotvb Rev. 00.05.24
	Flow Repeatability	+/- 0.15% of full scale
	DMM Asset / Cal Due Date	1445 July 31, 2018
	Temp. Asset / Cal Due date	800 June 25, 2018
	Date of calibration	May 11, 2018
	Suggested Recal Date	May 11, 2020
Calibration data	Ambient pressure	29.93 In Hg g.
	Ambient temperature	68.30 °F
	Gas	Air
	Calibration gas	Air
	Reference temperature	70.0 °F
	Reference pressure	14.696 PSI a
	Calibration pressure	20.00 PSI g.
	Calibration temperature	70.00 °F
	Dial-A-Gas Accuracy >50% FS (0.5% <50% FS)	CH4 ± 3% Full Scale, N2 ± 3% Full Scale
	Other	Q-Mix capable
	RFQ - SCR	

Calibration results

Flow						
Output 4-20 mA	**Indicated Flow SCFH**	**Actual Flow SCFH**	**Difference Allowable**	**Difference Actual**	**% Actual Error**	**Meter Verification Results**
4.000	0.000	0.000	**0.00000**	0.00000	0.0000	Passed
6.021	3531.698	3495.000	**166.01250**	36.69750	1.0500	Passed
9.985	10458.788	10485.000	**78.63750**	-26.21250	-0.2500	Passed
13.986	17450.535	17475.000	**131.06250**	-24.46500	-0.1400	Passed
17.982	24433.545	24465.000	**183.48750**	-31.45500	-0.1286	Passed

Temperature Accuracy +/- 1 °C						
Output 4-20 mA	**Indicated Temp. °F**	**Actual Temp. °F**	**Difference Allowable**	**Difference Actual**	**% Actual Error**	**Meter Verification Results**
7.358	69.778	70.6000	**1.8000**	-0.8225	-1.1650	Passed

Pressure Accuracy +/- 1% of XDR Full Scale						
Output 4-20 mA	**Indicated Press PSI a.**	**Actual Pressure PSI a.**	**Difference Allowable**	**Difference Actual**	**% Actual Error**	**Meter Verification Results**
N/A	N/A	N/A	**N/A**	N/A	N/A	N/A

Traceability Calibration of Sierra products is performed with equipment containing components which are tested and calibrated in accordance with ANSI/NCSL Z540 and/or ISO 17025 and are traceable to NIST. The results of this report relate only to the item calibrated or tested.

Calibration technician ____________ **Q.C.Technician** ____________

Warranty Registration To assure warranty service, register this instrument at www.sierrainstruments.com/register

SR form #: Sierra 8081 Rev. C SW: SR-0017, Rev. 1.02

Figure 35: Calibration certificate for Sierra Instruments Quadratherm 640i meter (serial number 218645)

QuadraTherm® 640i/780i | CALIBRATION CERTIFICATE

5 Harris Court, Building L • Monterey, California • (800) 866-0200 • (831) 373-0200 • Fax (831) 373-4402 • www.sierrainstruments.com

CERTIFICATE NUMBER 13713133248

PAGE 1 OF 1

Applicant/Customer	Name	STANFORD UNIVERSITY		
	Sales Order	205272		
	Purchase Order	CREDIT CARD		
Instrument	Model	640i-VT-2-L09-M1-E2-P2-V4-DD-0-2-8A-10		
	Serial number	308188		
	Tag #:	N/A		
	Input Power	24 Volt DC		
	Factory Flow Full Scale	1400.0	units	SCFM
	Temperature Full Scale	212.0	units	°F
	Pressure xdcr Full Scale	N/A	units	N/A
	Dial-A-Pipe Set up	4.026"		
	Accuracy DUT (+/-)	0.75% Rdg > 50% F/S	0.75% Rdg + 0.5% F/S < 50% F/S	
Calibration method	Calibration Station/Cal Due Date	Gas Loop Asset # 0709	June 25, 2022	
	Calibration Procedure	MFG-641		
	Software release	Gas Loop Calibration System, Robotvb Rev. 00.05.24		
	Flow Repeatability	+/- 0.15% of full scale		
	DMM Asset / Cal Due Date	1374	April 30, 2022	
	Temp. Asset / Cal Due date	800	June 25, 2022	
	Date of calibration	October 27, 2021		
	Suggested Recal Date	October 27, 2023		
Calibration data	Ambient pressure	29.93	In Hg g.	
	Ambient temperature	68.30	°F	
	Gas	Methane		
	Calibration gas	Methane		
	Reference temperature	70.0	°F	
	Reference pressure	14.696	PSI a	
	Calibration pressure	15.00	PSI g.	
	Calibration temperature	70.00	°F	
	Dial-A-Gas Accuracy >50% FS (0.5% <50% FS)	CO2 ± 3% Full Scale, N2 ± 3% Full Scale		
	Other RFQ - SCR	Q-Mix capable contact factory to activate		

Calibration results

Flow						
Output 4-20 mA	**Indicated Flow SCFM**	**Actual Flow SCFM**	**Difference Allowable**	**Difference Actual**	**% Actual Error**	**Meter Verification Results**
4.000	0.000	0.000	0.00000	0.00000	0.0000	Passed
7.964	346.806	349.027	9.61770	-2.22079	-0.6363	Passed
12.076	706.659	705.466	5.29099	1.19284	0.1691	Passed
16.136	1061.879	1061.445	7.96084	0.43431	0.0409	Passed
20.160	1414.000	1412.349	10.59262	1.65116	0.1169	Passed

Temperature Accuracy +/- 1.8 °F						
Output 4-20 mA	**Indicated Temp. °F**	**Actual Temp. °F**	**Difference Allowable**	**Difference Actual**	**% Actual Error**	**Meter Verification Results**
8.119	78.339	78.6620	1.8000	-0.3233	-0.4109	Passed

Pressure Accuracy +/- 1% of XDR Full Scale						
Output 4-20 mA	**Indicated Press PSI a.**	**Actual Pressure PSI a.**	**Difference Allowable**	**Difference Actual**	**% Actual Error**	**Meter Verification Results**
N/A	N/A	N/A	N/A	N/A	N/A	N/A

Traceability Calibration of Sierra products is performed with equipment containing components which are tested and calibrated in accordance with ANSI/NCSL Z540 and/or ISO 17025 and are traceable to NIST. The results of this report relate only to the item calibrated or tested.

Calibration technician ____________ Q.C.Technician ____________

Warranty Registration To assure warranty service, register this instrument at www.sierrainstruments.com/register

SI form #: Sierra 2001 Rev. C

SW: SM-0017, Rev. 1.03

Figure 36: Calibration certificate for Sierra Instruments Quadratherm 640i meter (serial number 308188)

Micro Motion, Inc.

Mass Flowmeter Calibration Certificate — **21175085**

Product Code	Serial ID	Order ID	Line	Item	Customer Tag
CMF050M319N2BAEZZZ	21175085	10437147	1.1	1	
PUCK800	26169890				

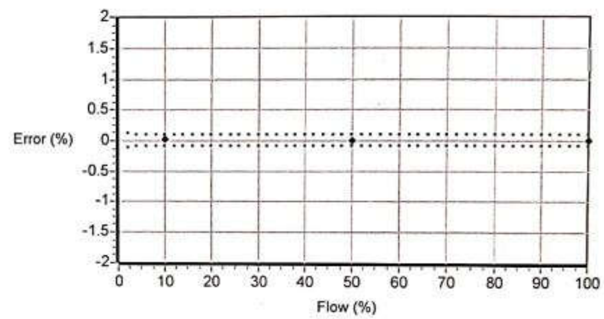
Process

Process ID : 1.36412429
Process Time : 2021.09.21 21:11:37
Process Stand : TSM1C@SSCB:1
Stand Uncertainty : +/-0.030%
Fluid : H20
100% Rate : 56.7 KG/MIN
Pickoff : 1
Max Rate P/T : 50.03 PSIG/22.7 C

Results

Status : PASS
D1 : 0
D2 : 1
K1 : 6366.231
K2 : 7630.057
DT : 4.5
FD : 342.6751
DTG : 0
DFQ1 : 0
DFQ2 : 0
FlowCal : 15.7464.29
FFQ : 0
FTG : 0
DensCal : 06366076304.50
FCF : 15.746
FT : 4.29

Detail



Flow (%)	Flow Rate (kg/min)	Meter Total (kg)	Reference Total (kg)	Error (%)	Specification (±%)
100.0	56.7	57.38985	57.39551	-0.010	0.100
10.0	5.67	5.649494	5.648243	0.022	0.100
50.0	28.35	27.98996	27.99243	-0.009	0.100
100.0	56.7	57.26417	57.26926	-0.009	0.100

BIJAY KHALING
Technician
This certificate is produced by an electronic data system and is valid without signature.

Traceable to one or more of the following National Metrology Institutes: NIM-China, NIST-USA, and VSL-The Netherlands 26.0.0.281 2021.09.21 21:28:41 1/1

Figure 37: Calibration certificate for Micro Motion ELITE Coriolis meter (serial number: 21175085)

DESERT GAS, L.P. EHRENBERG, ARIZONA 10/15/2021 1:39:06 PM

LNG CHROMATOGRAPH REPORT Week of Oc

Last Sample Time	10/16/2021 13:34
Hexane+ (C6,7,8..)	0.000Mole%
Propane (C3)	0.086Mole%
isoButane (iC4)	0.000Mole%
nButane (nC4)	0.000Mole%
neoPentane (neoC5)	0.000Mole%
isoPentane (iC5)	0.000Mole%
nPentane (nC5)	0.000Mole%
Nitrogen (N2)	0.485Mole%
Methane (C1)	96.125Mole%
Carbon-Dioxide (CO2)	0.000Mole%
Ethane (C2)	3.303Mole%
Dry Heat	1036.1BTU/cf
Saturated Heat	1018.0BTU/cf
Specific Gravity	0.574
Compressibility	1.002
Wobbe Index	1367.9BTU/scf

The Desert Gas chromatograph data report is accurate to within the limits of the measuring equipment. The report data is an accurate representation of the produced LNG delivered to the trailer. If LNG production is batched, sample date may not match BOL shipped date, however the compositional data will be accurate.

BOL#

Operator: Derick [illegible]

Desert Gas, LP
PO Box 140
50660 Colorado River Road
Ehrenberg AZ, 85334

DESERT GAS, L.P. EHRENBERG, ARIZONA 10/19/2021 2:37:13 AM

LNG CHROMATOGRAPH REPORT Weeks of Oc

Last Sample Time	10/19/2021 02:21
Hexane+ (C6,7,8..)	0.000Mole%
Propane (C3)	0.155Mole%
isoButane (iC4)	0.008Mole%
nButane (nC4)	0.009Mole%
neoPentane (neoC5)	0.000Mole%
isoPentane (iC5)	0.000Mole%
nPentane (nC5)	0.000Mole%
Nitrogen (N2)	0.260Mole%
Methane (C1)	95.224Mole%
Carbon-Dioxide (CO2)	0.000Mole%
Ethane (C2)	4.344Mole%
Dry Heat	1047.8BTU/cf
Saturated Heat	1029.6BTU/cf
Specific Gravity	0.579
Compressibility	1.002
Wobbe Index	1377.3BTU/scf

The Desert Gas chromatograph data report is accurate to within the limits of the measuring equipment. The report data is an accurate representation of the produced LNG delivered to the trailer. If LNG production is batched, sample date may not match BOL shipped date, however the compositional data will be accurate.

BOL#

Operator: Michael Dominguez

Desert Gas, LP
PO Box 140
50660 Colorado River Road
Ehrenberg AZ, 85334

DESERT GAS, L.P. EHRENBERG, ARIZONA 10/25/2021 4:48:35 PM

LNG CHROMATOGRAPH REPORT week of C

Last Sample Time	10/25/2021 16:29
Hexane+ (C6,7,8..)	0.006Mole%
Propane (C3)	0.165Mole%
isoButane (iC4)	0.019Mole%
nButane (nC4)	0.026Mole%
neoPentane (neoC5)	0.000Mole%
isoPentane (iC5)	0.000Mole%
nPentane (nC5)	0.027Mole%
Nitrogen (N2)	0.197Mole%
Methane (C1)	96.270Mole%
Carbon-Dioxide (CO2)	0.000Mole%
Ethane (C2)	3.292Mole%
Dry Heat	1042.1BTU/cf
Saturated Heat	1024.0BTU/cf
Specific Gravity	0.575
Compressibility	1.002
Wobbe Index	1374.9BTU/scf

The Desert Gas chromatograph data report is accurate to within the limits of the measuring equipment. The report data is an accurate representation of the produced LNG delivered to the trailer. If LNG production is batched, sample date may not match BOL shipped date, however, the compositional data will be accurate.

BOL#

Operator: Roger Middlebrook

Desert Gas, LP
PO Box 140
50660 Colorado River Road
Ehrenberg AZ, 85334

Figure 38: Chromatography reports of gas composition for tests conducted in Ehrenberg, Arizona. From left to right: (i) October 10-16 releases, (ii) October 17-23 releases, and (iii) October 24-30 releases.

ATMOS Energy - West Texas Division

P. O. Box 1121
Lubbock, TX 79408

7/29/2021 5:14 PM
Luna, Jose

Chromatograph Report

from Contract Day 06/01/2021 to Contract Day 06/30/2021

Station ID: 8000100890
Analysis ID: 8000100890
Analysis Name: MIDLAND PURCHASE POINT #2
Company Name: ATMOS ENERGY - WEST TEXAS

Effective Date	Sat. HV	As Del HV	Dry HV	Meas. HV	Water Content	Wobbe	Real Gravity	C1	C2	C3	IC4	NC4	IC5	NC5	C6	C7	C8	C9	C10	N2	CO2	O2	H2O	CO	H2S	H2	He
06/01/2021 09:00	1047.4	1066.1	1066.1	0.0		1348.5	0.6250	86.2647	9.1038	1.0965	0.0133	0.0195	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	3.4700	0.0322	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
06/02/2021 09:00	1052.0	1070.7	1070.7	0.0		1352.3	0.6269	86.0076	9.2921	1.2427	0.0159	0.0232	0.0003	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	3.4140	0.0043	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
06/03/2021 09:00	1046.2	1064.8	1064.8	0.0		1348.6	0.6234	86.5148	8.9839	1.0346	0.0122	0.0175	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	3.4273	0.0095	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
06/04/2021 09:00	1041.3	1059.9	1059.9	0.0		1344.6	0.6213	86.8170	8.7420	0.8968	0.0104	0.0143	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	3.4687	0.0507	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
06/05/2021 09:00	1048.6	1067.3	1067.3	0.0		1349.2	0.6257	86.1962	9.0908	1.1741	0.0154	0.0227	0.0003	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	3.4736	0.0268	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
06/06/2021 09:00	1054.1	1072.9	1072.9	0.0		1352.6	0.6291	85.7678	9.3264	1.3850	0.0194	0.0298	0.0005	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	3.4158	0.0552	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
06/07/2021 09:00	1057.6	1076.4	1076.4	0.0		1355.5	0.6306	85.5685	9.4581	1.5055	0.0214	0.0331	0.0007	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	3.3936	0.0190	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
06/08/2021 09:00	1056.2	1075.1	1075.1	0.0		1354.8	0.6297	85.6991	9.4088	1.4368	0.0203	0.0316	0.0006	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	3.3751	0.0276	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
06/09/2021 09:00	1051.8	1070.5	1070.5	0.0		1351.0	0.6279	85.9681	9.1614	1.3335	0.0180	0.0275	0.0005	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	3.4345	0.0563	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
06/10/2021 09:00	1048.2	1066.9	1066.9	0.0		1348.5	0.6259	86.2270	9.0167	1.1991	0.0148	0.0216	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	3.4489	0.0717	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
06/11/2021 09:00	1058.5	1077.4	1077.4	0.0		1355.1	0.6321	85.3598	9.5267	1.5788	0.0216	0.0327	0.0007	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	3.4306	0.0491	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
06/12/2021 09:00	1048.1	1066.7	1066.7	0.0		1348.6	0.6257	86.2620	8.9792	1.2031	0.0156	0.0235	0.0003	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	3.4661	0.0502	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
06/13/2021 09:00	1048.0	1066.6	1066.6	0.0		1349.5	0.6247	86.3767	8.9505	1.1755	0.0152	0.0224	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	3.4582	0.0013	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
06/14/2021 09:00	1044.8	1063.4	1063.4	0.0		1346.9	0.6233	86.5616	8.8254	1.0684	0.0133	0.0190	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	3.4882	0.0241	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
06/15/2021 09:00	1040.4	1058.9	1058.9	0.0		1344.2	0.6206	86.9023	8.6587	0.8869	0.0100	0.0128	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	3.5239	0.0054	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
06/16/2021 09:00	1052.7	1071.4	1071.4	0.0		1346.4	0.6333	85.3216	9.3510	1.4789	0.0215	0.0342	0.0007	0.0003	0.0000	0.0000	0.0000	0.0000	0.0000	3.4389	0.3529	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
06/17/2021 09:00	1054.3	1073.1	1073.1	0.0		1347.1	0.6346	85.1271	9.4783	1.5321	0.0221	0.0346	0.0008	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	3.4348	0.3700	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
06/18/2021 09:00	1058.9	1077.8	1077.8	0.0		1349.8	0.6375	84.7467	9.6645	1.7188	0.0271	0.0443	0.0010	0.0005	0.0000	0.0000	0.0000	0.0000	0.0000	3.4237	0.3734	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
06/19/2021 09:00	1065.9	1084.9	1084.9	0.0		1354.0	0.6420	84.1816	9.9102	2.0248	0.0346	0.0579	0.0016	0.0007	0.0000	0.0000	0.0000	0.0000	0.0000	3.4139	0.3748	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
06/20/2021 09:00	1058.2	1077.1	1077.1	0.0		1349.6	0.6369	84.8476	9.6019	1.6956	0.0268	0.0433	0.0010	0.0004	0.0000	0.0000	0.0000	0.0000	0.0000	3.4083	0.3751	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
06/21/2021 09:00	1053.0	1071.7	1071.7	0.0		1346.4	0.6336	85.2905	9.3567	1.5005	0.0217	0.0338	0.0007	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	3.4275	0.3684	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
06/22/2021 09:00	1053.6	1072.3	1072.3	0.0		1346.6	0.6341	85.2274	9.3688	1.5331	0.0235	0.0375	0.0009	0.0003	0.0000	0.0000	0.0000	0.0000	0.0000	3.4373	0.3713	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
06/23/2021 09:00	1050.1	1068.8	1068.8	0.0		1344.2	0.6322	85.4780	9.2036	1.4211	0.0208	0.0321	0.0007	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	3.4737	0.3700	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
06/24/2021 09:00	1060.4	1079.3	1079.3	0.0		1350.7	0.6384	84.6560	9.6688	1.8003	0.0300	0.0491	0.0012	0.0004	0.0000	0.0000	0.0000	0.0000	0.0000	3.4238	0.3703	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
06/25/2021 09:00	1053.1	1071.9	1071.9	0.0		1346.1	0.6340	85.2363	9.3488	1.5275	0.0232	0.0369	0.0008	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	3.4583	0.3680	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
06/26/2021 09:00	1030.8	1049.1	1049.1	0.0		1336.5	0.6162	88.2321	7.0979	1.0364	0.0161	0.0265	0.0009	0.0005	0.0000	0.0000	0.0000	0.0000	0.0000	3.3666	0.2230	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
06/27/2021 09:00	1006.8	1024.8	1024.8	0.0		1323.3	0.5997	90.7401	5.2934	0.3850	0.0045	0.0060	0.0002	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	3.4857	0.0850	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
06/28/2021 09:00	1052.6	1071.3	1071.3	0.0		1345.4	0.6341	85.0659	9.5989	1.4235	0.0176	0.0243	0.0003	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	3.5003	0.3690	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
06/29/2021 09:00	1052.5	1071.3	1071.3	0.0		1345.0	0.6344	85.0633	9.5277	1.4656	0.0191	0.0279	0.0005	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	3.5272	0.3688	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
06/30/2021 09:00	1054.2	1073.0	1073.0	0.0		1346.5	0.6350	85.0235	9.5457	1.5316	0.0204	0.0303	0.0006	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	3.4785	0.3694	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Flow Weighted Average:	1049.9	1068.6	1068.6	0.0			0.6287	85.9152	9.0859	1.3282	0.0185	0.0284	0.0005	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	3.4466	0.1766	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Figure 39: Chromatography reports of gas composition for tests conducted in Ehrenberg, Arizona.