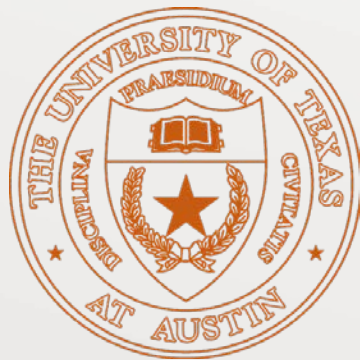


Methane Emissions from Process Equipment at Natural Gas Production Sites in the United States: Pneumatic Controllers



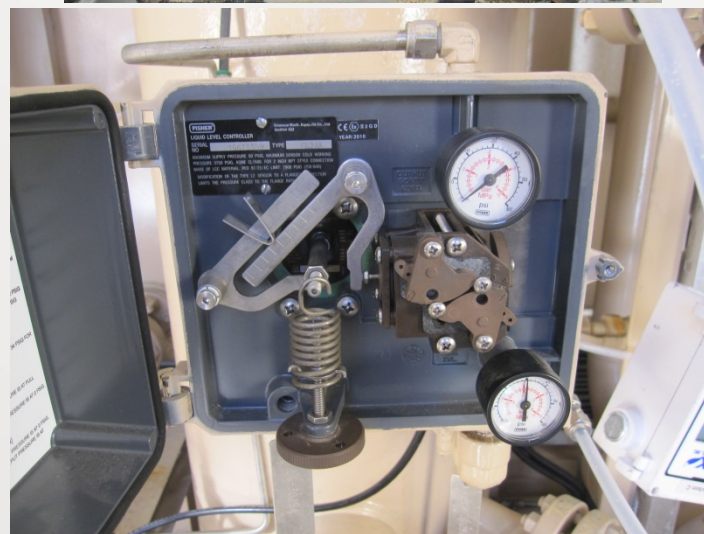
Need for Study



- Methane, the primary constituent of natural gas, is a potent greenhouse gas
- Pneumatic controllers are estimated to be among the larger sources of methane emissions from the natural gas supply chain; recent measurements indicate current emission estimates may be low
 - Average emissions per controller in most recent US EPA national inventory (334 Gg/477,606 devices = 0.70 Mg/yr = 4.2 scf methane/hr)
 - Average emissions per controller in measurements reported by Allen, et al. (2013) for hydraulically fractured well sites was more than double the EPA average rate (10.5 scf methane/hr), however, these measurements were exclusively for hydraulically fractured wells in shale formations; average emission rates were dominated by a subset of devices with high emissions
 - Emissions similar to those reported by Allen, et al. (2013) measured in 2013 in British Columbia and Alberta in a study targeting high emission devices
- To better inform policy, measurements are needed to (i) quantify methane emissions from pneumatic controllers at a diverse set of sites, and (ii) characterize the population of high emitting devices.

Pneumatic Controllers

- Pneumatic controllers on natural gas production sites use gas pressure to control the operation of mechanical devices (valves), and emit gas as they open and close the valves
- The valves control process conditions such as levels, temperatures and flow rates.
- U.S. EPA reports 477,606 controllers are in use at natural gas production sites in the United States.



Classifying controller types and types of controller service

- Types of controllers
 - Intermittent vent
 - Continuous vent
- Types of controller service
 - On/off and throttling can be either continuous vent or intermittent vent
- Application
 - Controllers are used in applications such as separators, compressors, plunger lifts, and others.
- Equipment manufacturer and model
 - Same make and model might be configured in multiple manners
- EPA categories
 - Low bleed, High bleed, Intermittent
- **This work uses as its primary classification continuous vent and intermittent vent (based on the measured emission pattern);**
operator EPA classification and on-site classification as on/off or throttling are provided in Supporting Information

Emission measurement methods

(measurements of gas entering and/or leaving the controller)

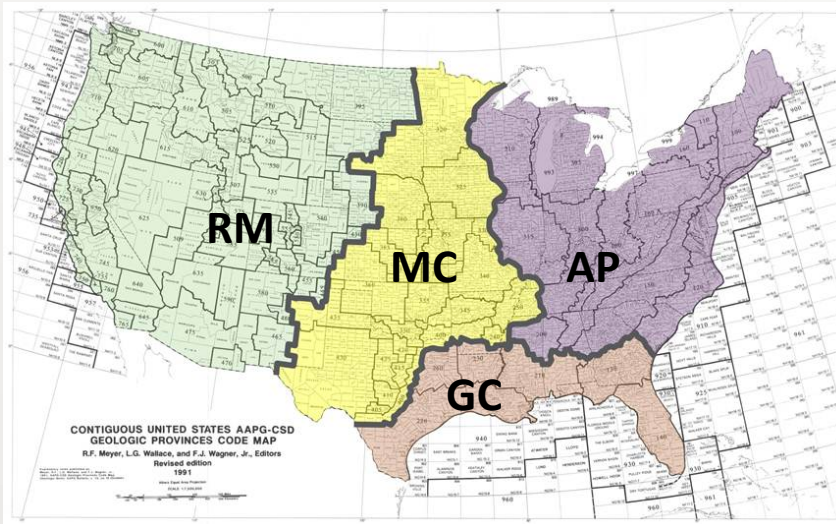
Supply line measurements
(primary measurement)



Exhaust measurements
(secondary/QC measurement)



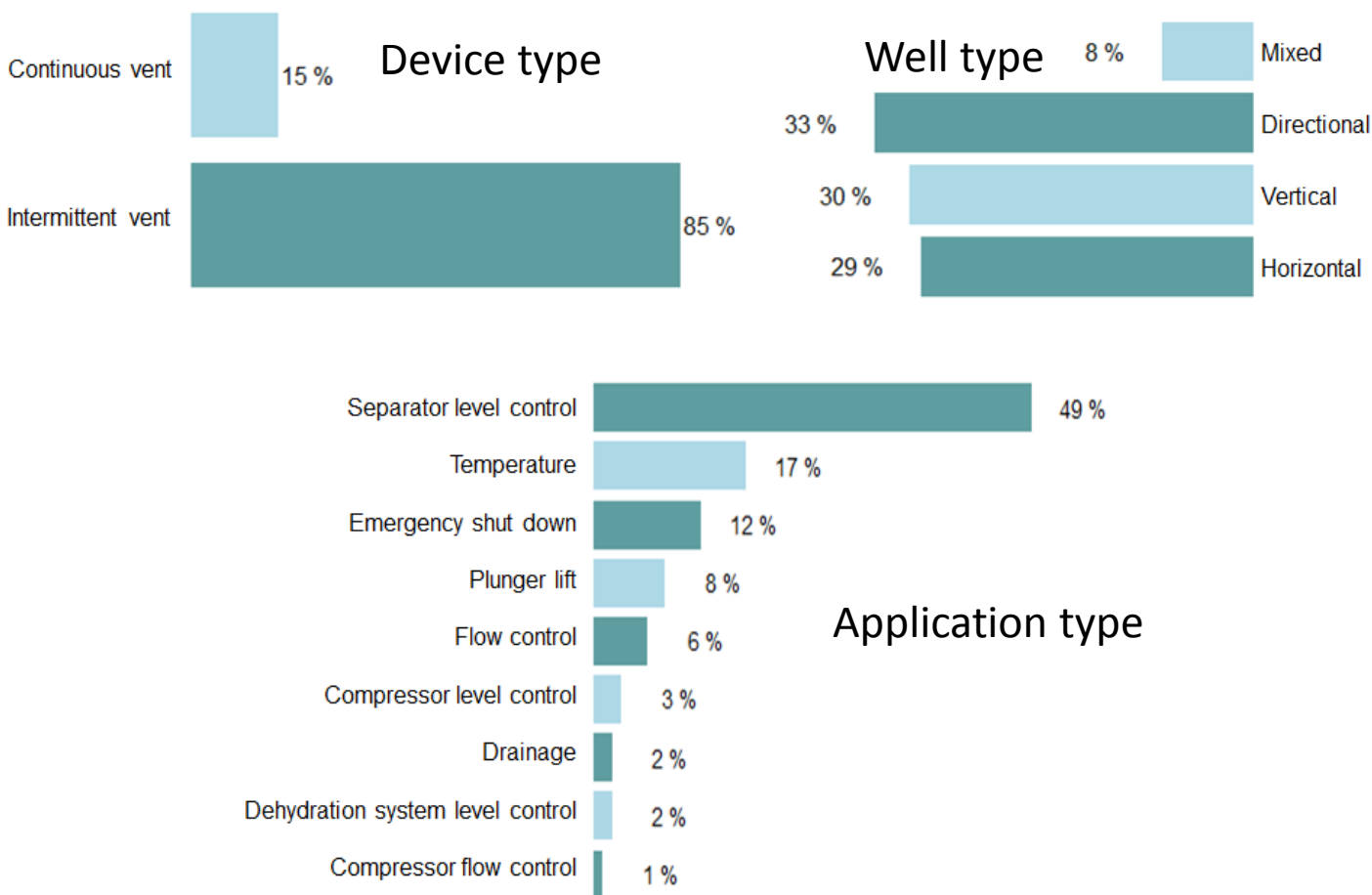
Geographic Distribution of Measurements



- 377 unique devices
- ~400 measurements
- Measured both unconventional and conventional well sites

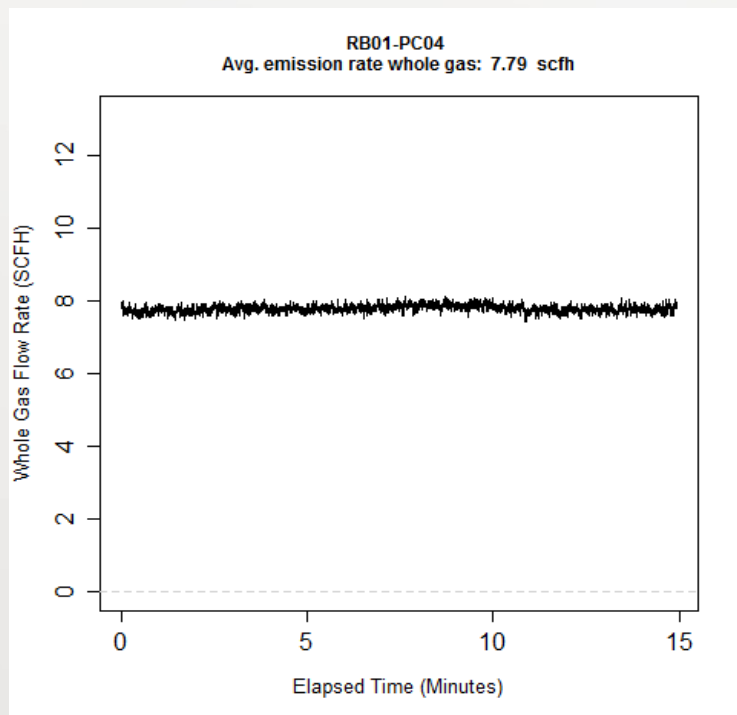
Region	Percent of Devices Sampled
AP	13.8%
GC	32.6%
MC	20.4%
RM	33.2%

Devices Sampled

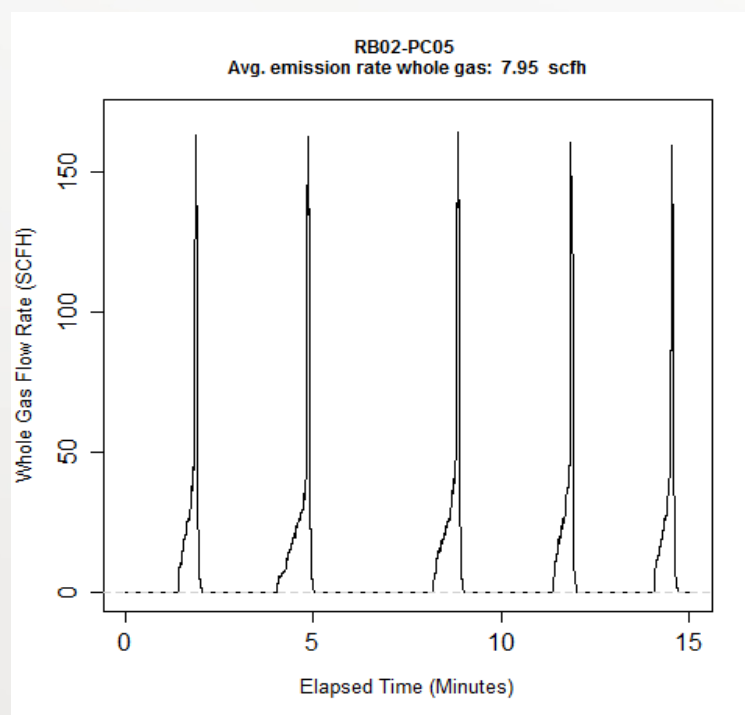


Examples of measurements (time series)

Continuous vent

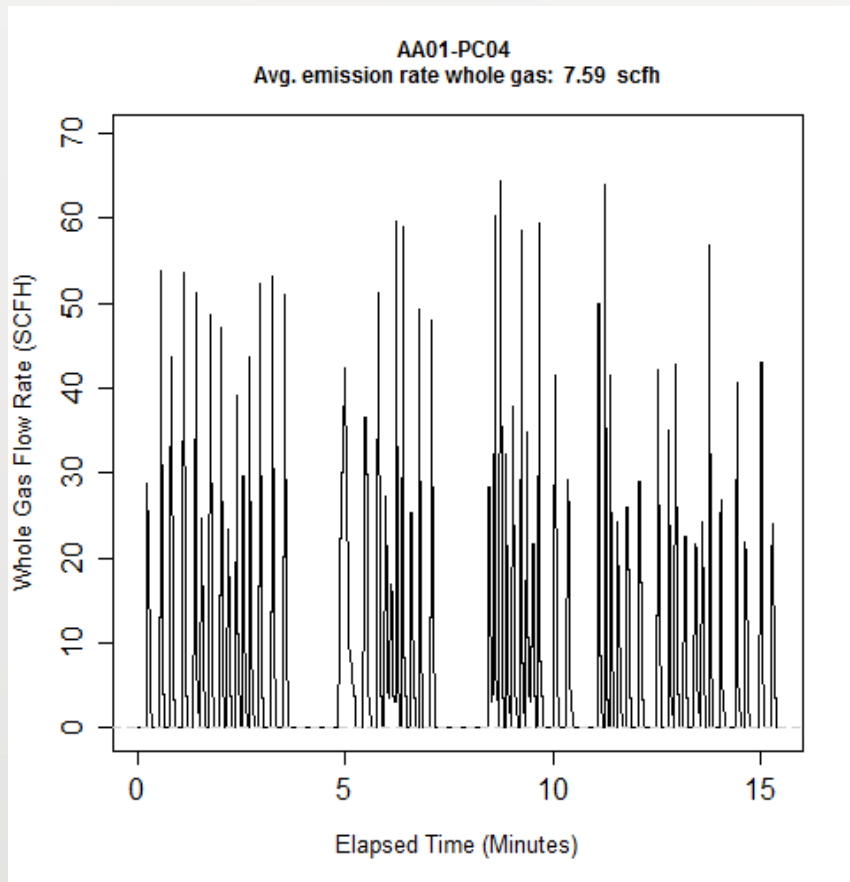


Intermittent vent

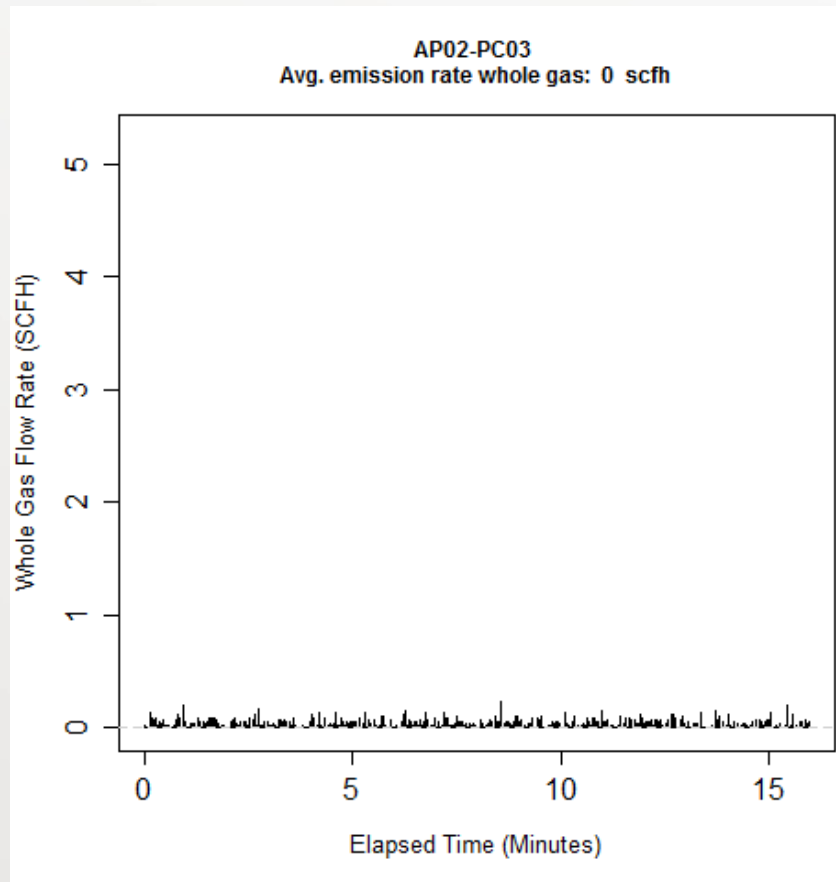


Time Series Examples

Intermittent vent
(~50 ACTUATIONS)

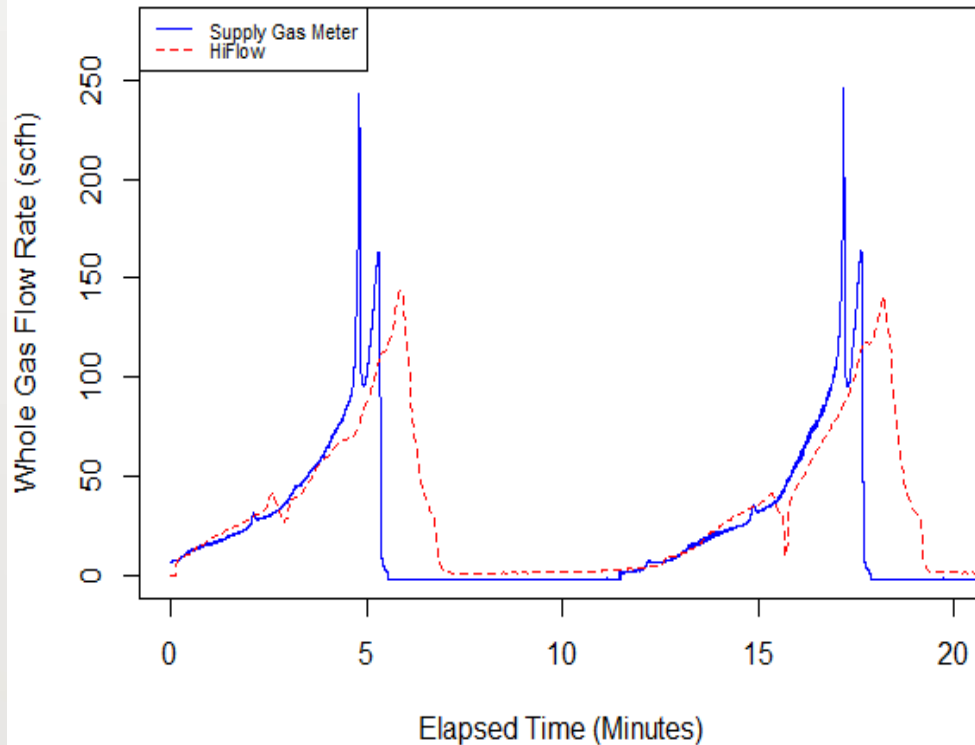


Intermittent vent
(0 ACTUATIONS)



Measurement inter-comparison

Supply Gas Meter vs. HiFlow device

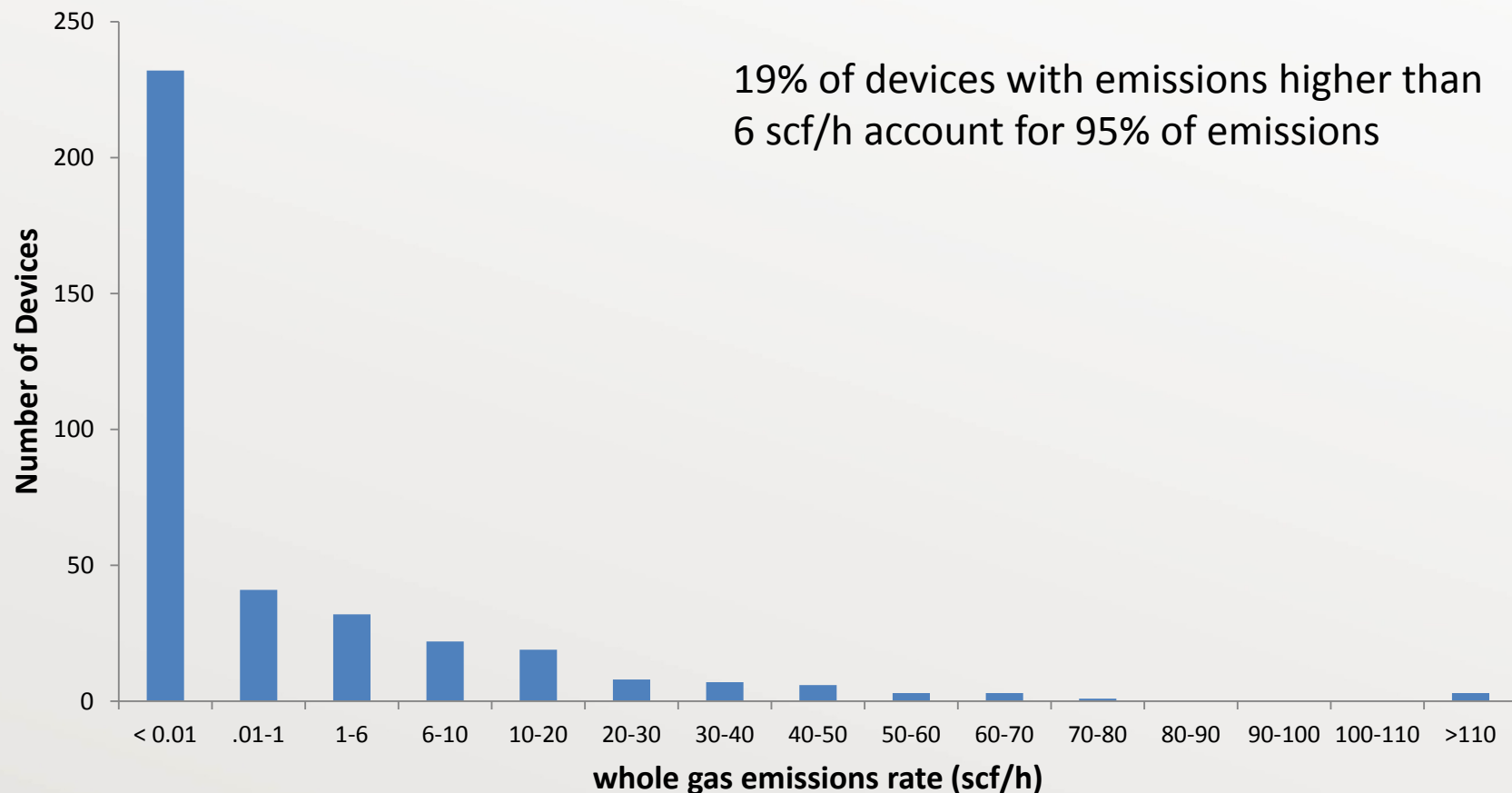


Comparison of supply gas meter (blue line) and modified HiFlow measurements (red line) for a water level controller on a separator. For this controller, the average emission rate measured by the supply gas meter was 27 CFH vs. 34 CFH measured by the HiFlow sampler.

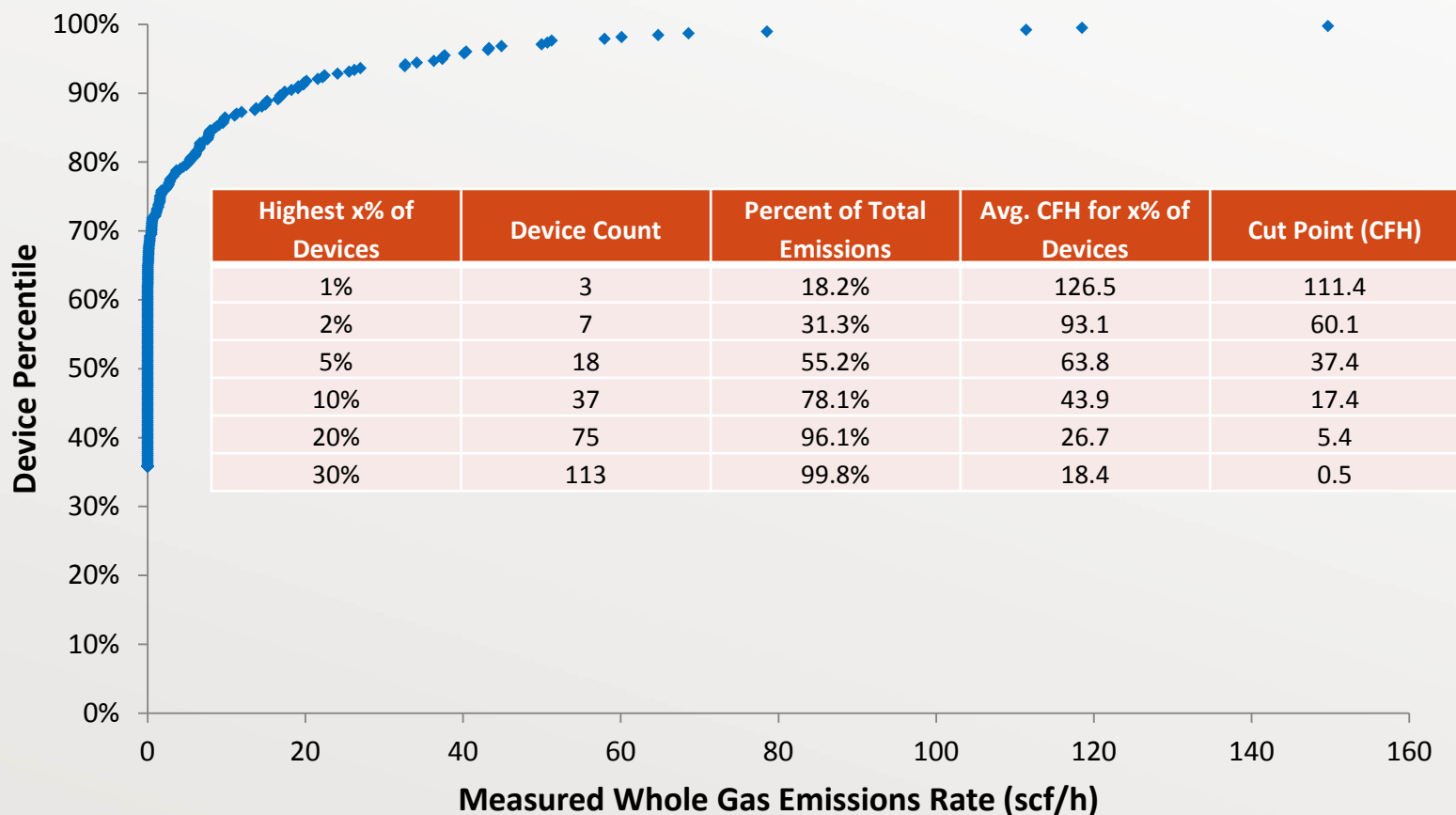
Findings

- A relatively small subset of devices dominate total emissions
- Pneumatic controllers in level control service on separators and in compressor service had higher emission rates than controllers in other types of service.
- Regional differences in emissions were observed, with the lowest emissions measured in the Rocky Mountains and the highest emissions in the Gulf Coast.
- Average emission rates per controller comparable to most recent EPA inventory estimates; controller count per well higher than recent EPA inventory estimates
- Analysis of the highest emitting devices suggests that many of these devices may not be operating as designed

A relatively small subset of devices dominate total emissions



A relatively small subset of devices dominate total emissions



Approach for estimating emissions of controllers with no emissions detected over 15 minutes

- Controllers assumed to be intermittent vent because a zero emission rate was observed
- Emissions rate = actuations/h * scf/actuation
- Scf/actuation determined based on data from observed actuations for similar application type (e.g., separator level control)
- Actuations/h estimated based on extrapolation of frequency data for separator level control
- These estimates add 2-11% to overall population average
- For clarity, these estimates will NOT be added to the data presented in this work

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Emissions depend on type of device being controlled

Average whole gas emission rates from controllers (scf/h), categorized by the application

Region	All Devices	Separator	Process Heater	Compressor	Wellhead	Plunger Lift	Dehydration System	Flare	Sales	Avg. w/o Compressor
AP	1.7	0.3	1.3	-	2.8	0.0	-	-	-	1.7
GC	11.9	16.3	-	10.6	0.0	7.3	4.3	0.0	0.0	12.0
MC	5.8	4.9	0.0	20.2	-	6.5	-	-	-	4.4
RM	0.8	1.5	0.2	-	0.4	0.1	0.0	0.0	-	0.8
Avg.	5.5	8.1	0.5	14.0	1.2	4.1	3.0	0.0	0.0	5.0

- More than 76% of devices measured with an emissions rate of greater than 6 scf/h were in service on compressors or as level controllers on separators.

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Regional variations in controller emissions

		Average whole gas emission rates from controllers (scf/h), categorized by the application								
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GC	11.9	16.3	-	10.6	0.0	7.3	4.3	0.0	0.0	12.0
MC	5.8	4.9	0.0	20.2	-	6.5	-	-	-	4.4
RM	0.8	1.5	0.2	-	0.4	0.1	0.0	0.0	-	0.8
Total	5.5	8.1	0.5	14.0	1.2	4.1	3.0	0.0	0.0	5.0

- The Rocky Mountain and Appalachian Regions have lower emission rates than the Mid-Continent and Gulf Coast regions and are less represented among the highest emitters.
- Continuous vent devices, with average whole gas emissions of 24.1 scf/h, were 21% of the controllers in the Gulf Coast and Mid-Continent regions, but only 9% in the Appalachian and Rocky Mountain regions

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National implications of measurements made in this work

$$\text{Emissions in a region} = EF_i * AF_i$$

EF_i = Emission Factor for region i (e.g., emissions per controller)

Emission factors based on measurements made in this work

AF_i = Activity Factor for region i (e.g. number of controllers)

Activity factors based on 2012 EPA national greenhouse gas inventory (EPA GHG NEI)

Comparisons to EPA 2012 Greenhouse Gas National Emission Inventory

Region	Count of Devices	Avg. Emission rate whole gas(scfh)	Avg. Emission rate methane (scfh)	Regional emissions (Gg/yr)
AP	77,261	1.70	1.65	21.5
GC	53,436	11.80	10.61	95.4
MC*	222,684	5.80	4.87	182.5
RM**	124,225	0.75	0.67	14.0
Total	477,606			313.4

*MC totals include equipment counts for Mid-Continent and Southwest regions reported in the 2012 EPA GHG NEI
 ** RM totals include equipment counts for Rocky Mountain and West Coast regions reported in the 2012 EPA GHG NEI

Number of controllers
(Activity data) from
2012 EPA GHG NEI

Emissions per controller
(Emission factor)
measured in this work

National emission
estimate (Activity data *
Emission factor)

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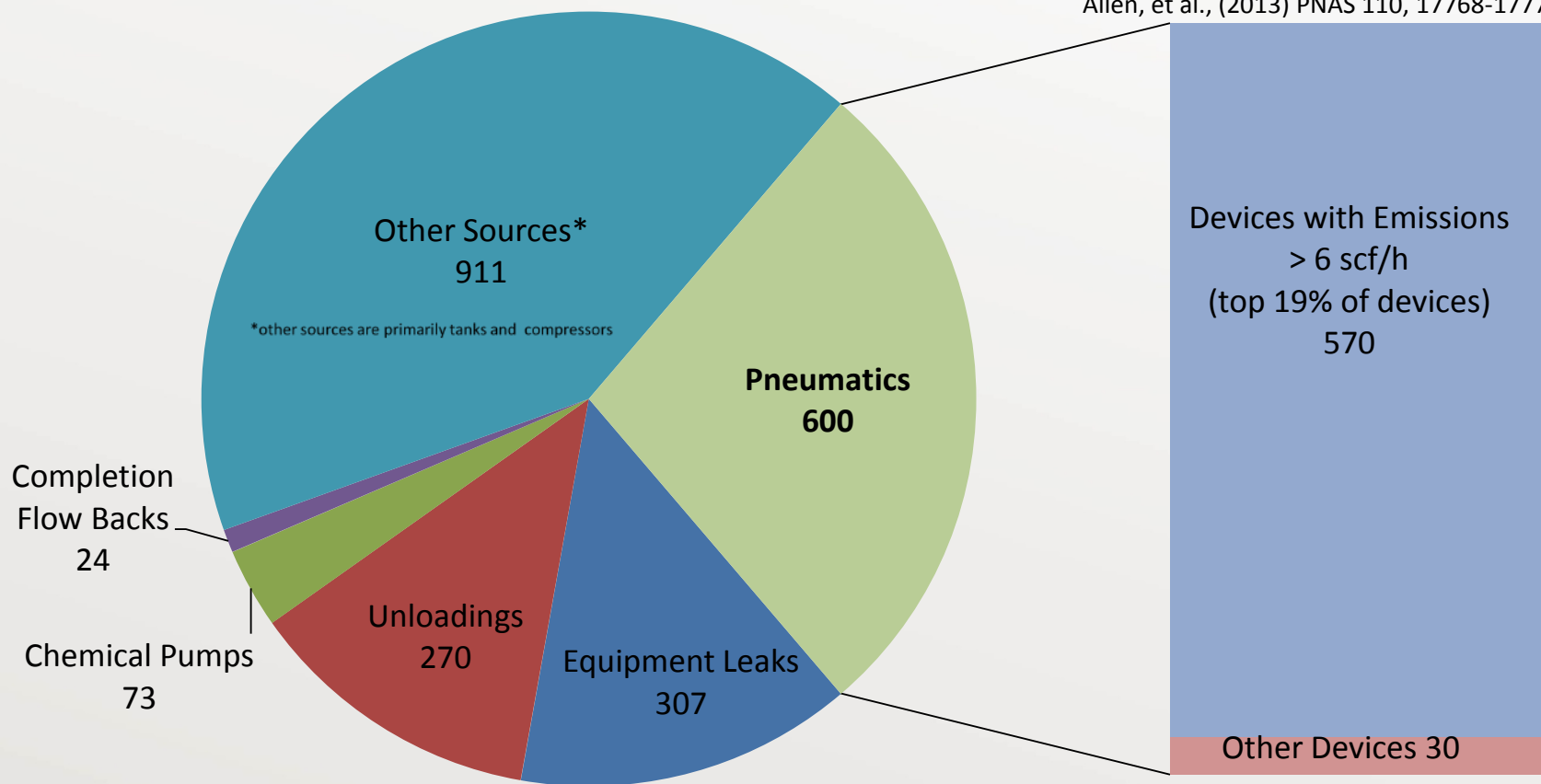
- Regional average emission rates multiplied by regional controller counts reported in the 2012 EPA national greenhouse gas emission inventory (2012 GHG NEI, released in 2014) gives a national methane emission estimate of 313 Gg/yr (approximately equal to the 2012 GHG NEI estimate of 334 Gg)
- National average of the emission rates (4.9 scfh methane) multiplied by the total national well count (470,913 wells) and controllers per well (2.7 controllers per well) gives a national emission estimate of more than double the estimate in the 2012 GHG NEI; assuming that 75% of wells in U.S. have 2.7 controllers/well and 75% are inventoried leads to an estimate of **600 Gg**.

Numbers of controllers

- Average number of controllers per well at sites measured: 2.7 (study team only sampled at sites with pneumatic controllers and sampled all controllers on site, including some that may not be inventoried for the EPA GHGRP or EPA NEI, such as emergency shut down controllers)
- Average number of controllers per well in EPA Greenhouse Gas National Emission Inventory: 1.0 (many wells have mechanical controllers)
- More observations on which to base activity data are needed (e.g., numbers of wells with no pneumatic controllers) Collecting national activity data was beyond the scope of this work

Estimated Annual Emissions from Upstream Natural Gas Production Sector in the United States (Gg Methane)

Estimate for pneumatic controllers: Emission factor from measurements in this work with activity data adjusted based on numbers of controllers per site observed in this work. Estimate for Unloadings: From updated measurements on unloadings, published in parallel with this work All other categories: Previously published by Allen, et al., (2013) PNAS 110, 17768-17773



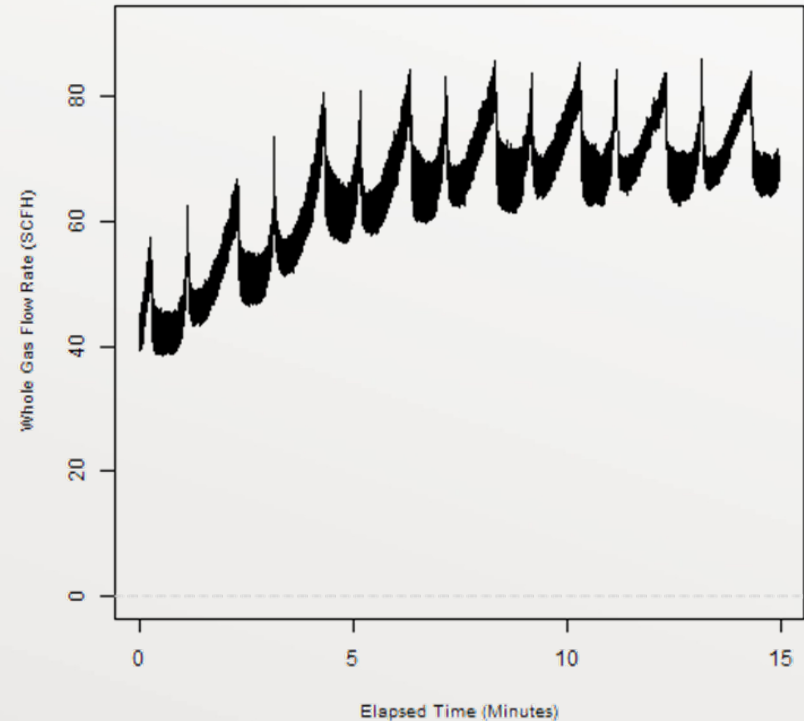
Total of 2180 Gg or 0.38% of 2012 U.S. natural gas withdrawals and production

Findings

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Representative emission time series for a controller not operating as designed

- Controller design leads to expectation that emission rate would return to zero between actuations



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Supplementary slides

Comparisons between this work and Allen, et al. (2013) data

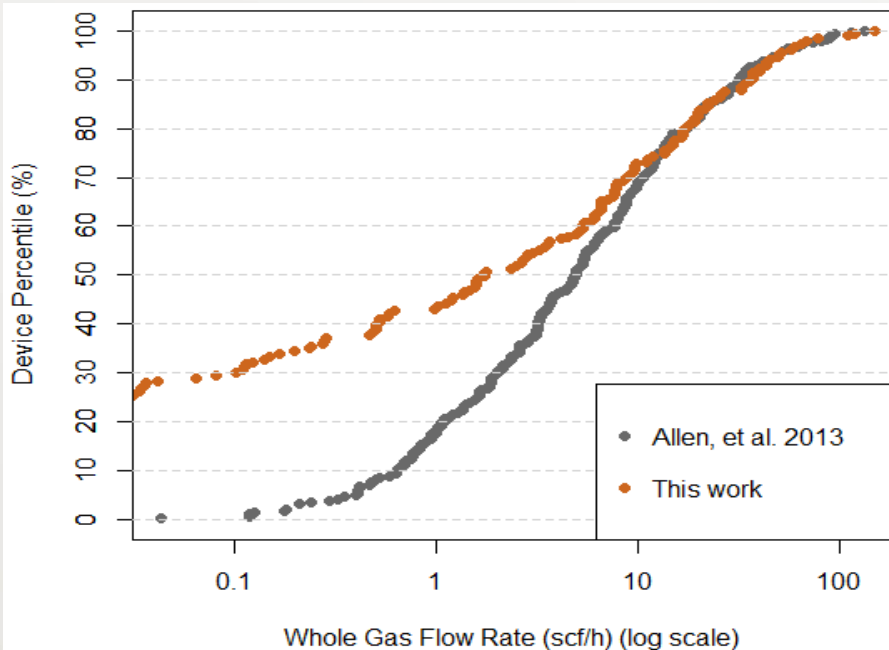
- Allen, et al. (2013; PNAS 110. 17768-17773)
 - All sites visited had been hydraulically fractured; average age < 2 years
 - Sites initially screened with infrared camera;
 - all measurements made with HiFlow device;
 - sampling captured approximately 40% of controllers on sites visited (attempt was to randomly select, but sampling was done after IR camera screening, which may have introduced bias)
 - Average emissions 10.5 scf/h methane (305 controllers)
 - Emissions highest in the Gulf Coast, lowest in the Rocky Mountains
 - 20% of devices account for 80% of emissions
- This work
 - Sites with a variety of ages and well types visited
 - Measurements made on all controllers at sites visited (unless precluded by operational or equipment issues)
 - Measurements made with in-line supply gas measurements, unless (~10% of devices) inserting measurement device into supply gas line was not possible
 - Average emissions of 4.9 scf/h methane (377 controllers)
 - Emissions highest in the Gulf Coast, lowest in the Rocky Mountains
 - 20% of devices account for 96% of emissions

Why the different average between Allen, et al. (2013) and this work?

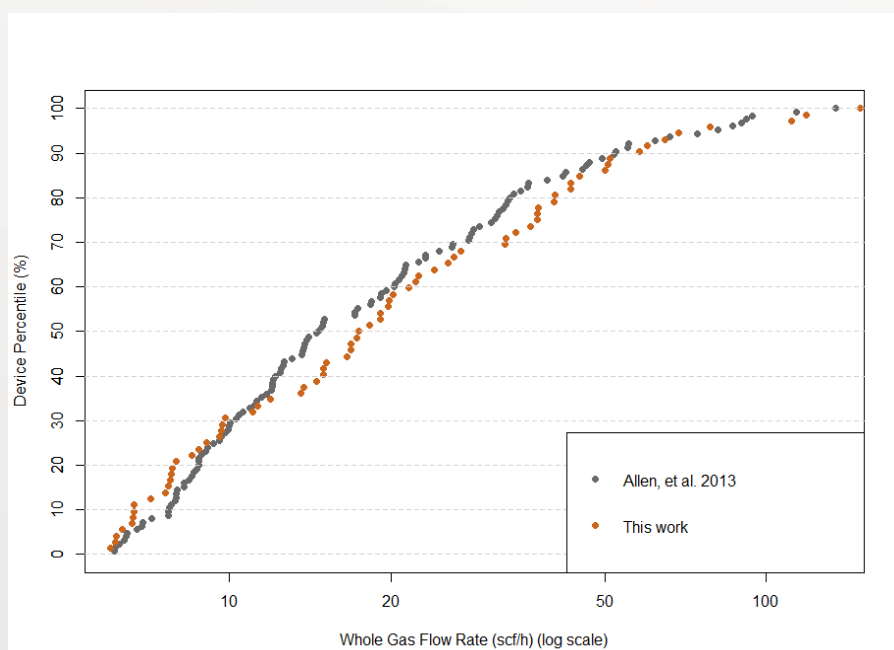
Primary reason is difference in number of very low <1 scf/h emission devices

Comparison of emission distribution data (This work vs. Allen, et al., 2013)

Emissions >0.01 scf/h (38% of devices)
(average per device of 14 scf/h)



Emissions >6 scf/h (19% of devices)
(average per device of 27 scf/h)



Why more very low emission devices in this work?

- All controllers on a site sampled, including ESD controllers (12% of controllers in this work), which some organizations do not include in emission reporting, and would not have been sampled by Allen, et al. (2013)
- Sampling by Allen, et al. (2013) was for samples with horizontal, hydraulically fractured wells; in this work, horizontal wells had controllers with average methane emissions of 5.9 scf/h, compared to 4.9 scf/h for the entire population
- May have been unintentional sample bias in Allen, et al. (2013) to devices with emissions detected using FLIR camera (~1.6 scf/h detection limit)