Spatially and temporally resolved emissions of light alkanes from oil and gas sources in shale gas production regions

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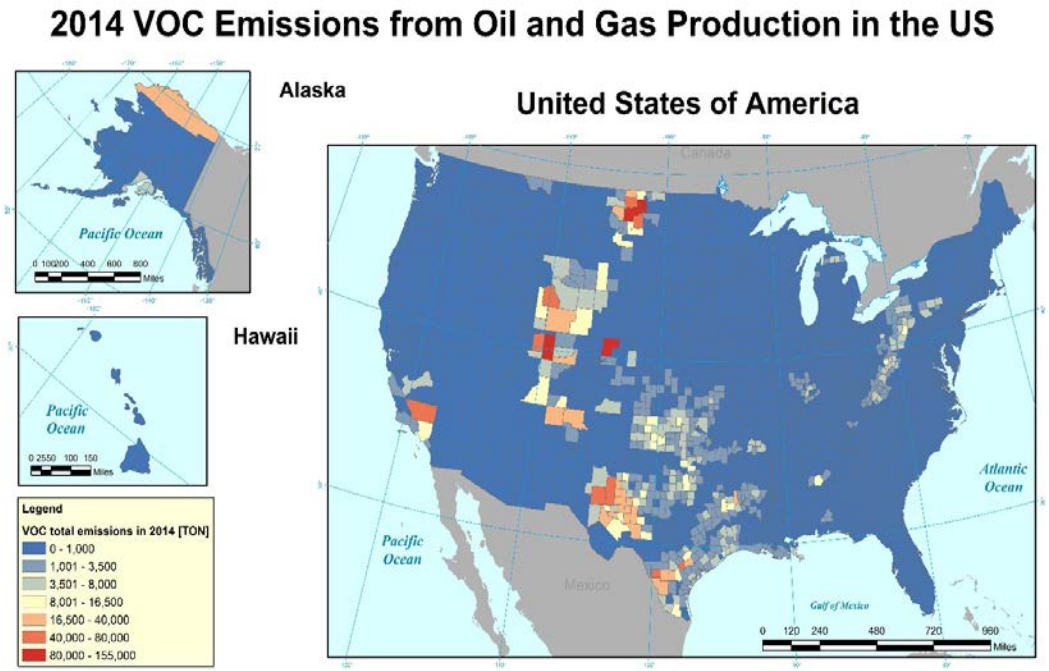
Motivation

- Many emission inventories for oil and gas production only report annual average emissions, and have coarse spatial resolution.
- Multiple uses of inventories (use in photochemical modeling; reconciliation with short duration observations) require fine scale spatial and temporal resolution.
- **Develop Emission Inventory (EI) that incorporates compositions, km scale spatial resolution, and hourly temporal resolution.**



Overview

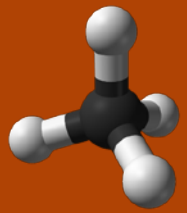
Molecular fingerprints of emissions

Temporally resolved emission magnitudes by source

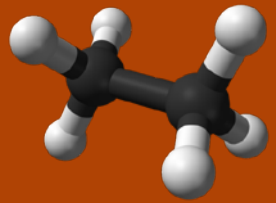
Emission inventory

Molecular Fingerprints of Emissions

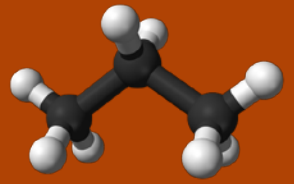
- Methane (C1)



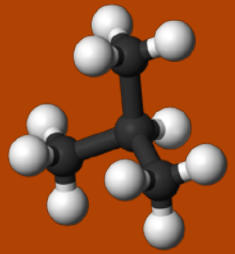
- Ethane (C2)



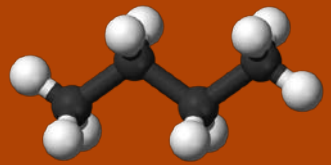
- Propane (C3)



- Isobutane (iC4)

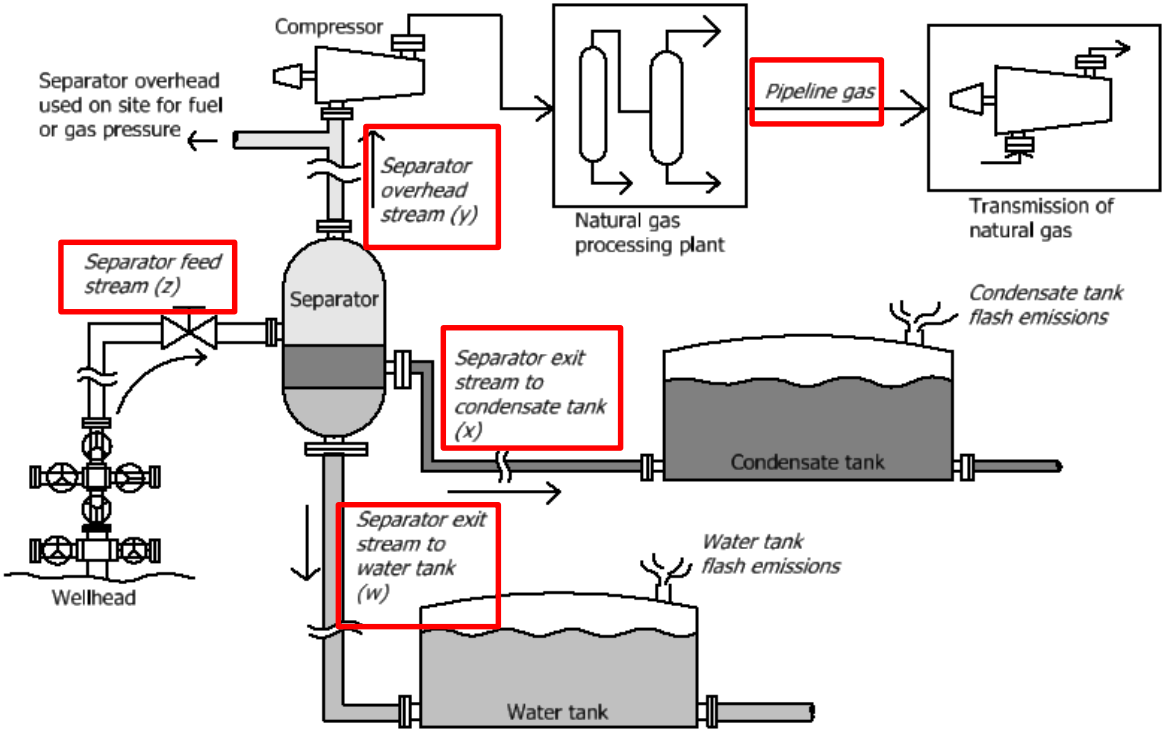


- Butane (C4)



Molecular Fingerprints of Emissions

- Hydrocarbon wells produce:
  - C1, C2, C3, C4, C5, C6, C7, C8+, H_2S, H_2O, N_2, CO_2 but varies by basin
- Emission factors tend to report methane emissions; composition ratios used to estimate other emissions.



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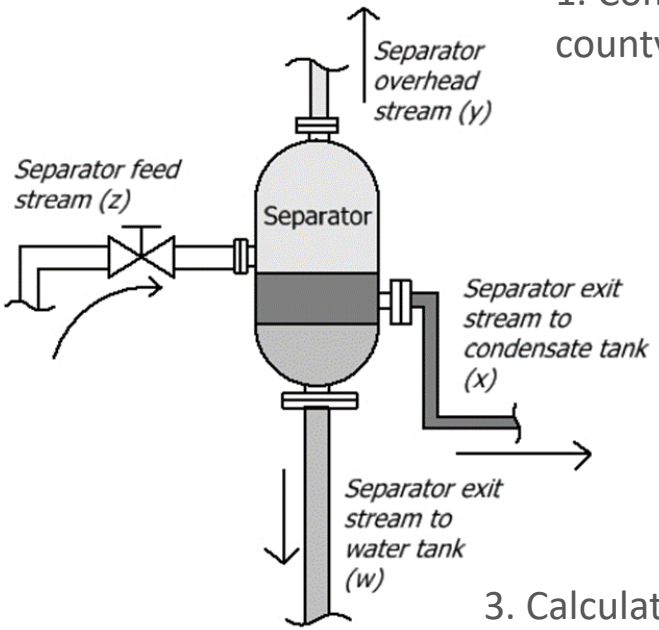
Molecular Fingerprints of Emissions

Estimating compositions of emissions

1. Composition available (per county).



2. Calculated using a thermodynamic model, based on Peng-Robinson Equation of State (PR-EOS).

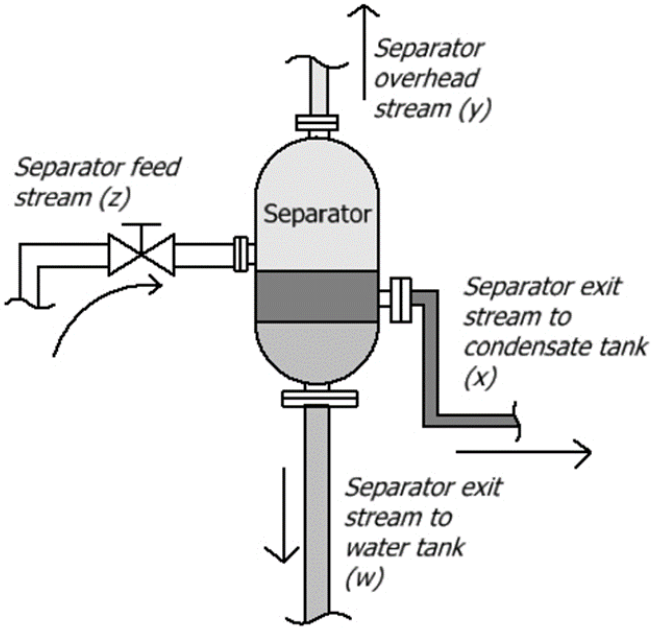
3. Calculated using a thermodynamic model, based on Henry's Law.

4. Estimated using mass balance. Flowrates of produced gas, condensate and water are available.

Molecular Fingerprints of Emissions

Summary

- Separator feed and separator overhead found to be very similar.
  - Assumed that separator feed = separator overhead composition.
- Ethane to methane ratio in condensate tank vent ~6x the ratio in separator overhead.
- Pipeline gas composition taken as the separator overhead from the county with the most methane and least amount of other species.
- Ratios of ethane, propane, isobutane and butane to methane (Ci/C1) determined for each of the different streams (separator overhead, condensate tank flash, water tank flash) in each county of the Barnett Shale.



Emission Sources

- Allocate composition profiles to sources.
- Spatially allocate activity data.
- Assign emission factors.
  - Intermittent vs. continuous sources.

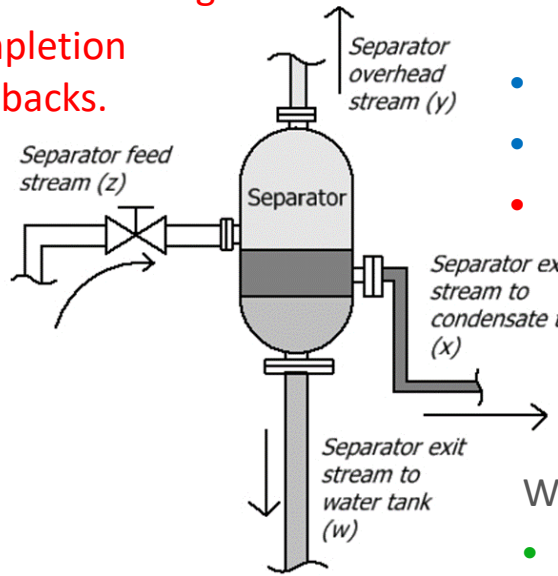
Pacsi, Adam P., et al. "Regional ozone impacts of increased natural gas use in the Texas power sector and development in the Eagle Ford shale." *Environmental science & technology* 49.6 (2015): 3966-3973.

Emission Sources

Allocation of emissions

Legend
- Continuous emissions
- Intermittent emissions
- Continuous and intermittent emissions

Separator feed:
- Liquid Unloadings.
- Completion flowbacks.



Separator overhead:
- Chemical injection pump.
- Compression systems:
  - Fugitive emissions
  - Engine exhaust.
  - Compressor start-up.
  - Compressor blowdowns.
- Dehydrators.
- Pneumatic controllers.
- Un-inventoried high-emitters.

Randomly selected composition:
- Equipment leaks.

Pipeline gas composition:
- Midstream sites.

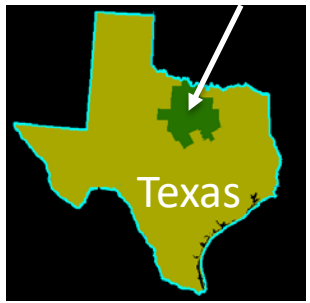
Condensate tank flash:
- Condensate flashing.

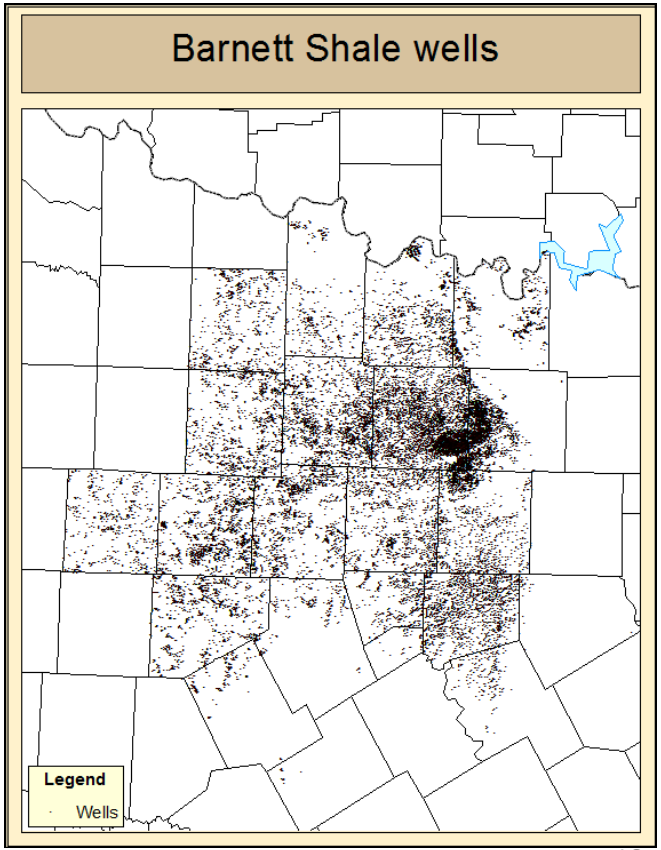
Water tank flash:
- Water flashing.

Emission Sources

EI Spatial resolution

- Location of wells and midstream sites is known.
- Total counts of equipment in the Barnett Shale (activity factors) can be derived from EPA's Greenhouse Gas Reporting Program (GHGRP).





Emission Sources

Emission rates

$$Emission = \sum_i ActivityFactor_i \cdot EmissionFactor_i$$

- Emission factors are not fixed values, but distributions drawn from recent methane emission measurement studies; emission factors for methane (C_1) are sampled (with replacement) from measurements from each of the sources.
- Emission of light hydrocarbons (C_2 to C_4) are estimated using C_i/C_1 ratios.
- Monte-Carlo model generates 1,000 hourly instances.

Emission Sources

Emission Factors for intermittent sources

- Compressor start-ups:
  - GHGRP data used to estimate how many start-up events would occur at any given hour in the Barnett Shale (average ±uncertainty). Assumed events last one hour.
  - Each hourly simulation samples from distribution to determine number of start-ups occurring in that hour. Randomly assign start-up events to sites with compressors.
  - Each start-up event samples emission rate from distribution of measurements, with replacement.
- Similar approach for other intermittent sources.
  - Completion flowbacks: randomly select if there is flare or recovery of emissions; venting not allowed for 2013.
  - Condensate tanks: assumed that highest emission rate sources, accounting for 60% of production, have controls
  - Liquid unloadings: Randomly select location from wells that report unloading emissions; for wells with manual unloadings, assume emissions occur during working hours; select emissions from distributions of measured emissions.

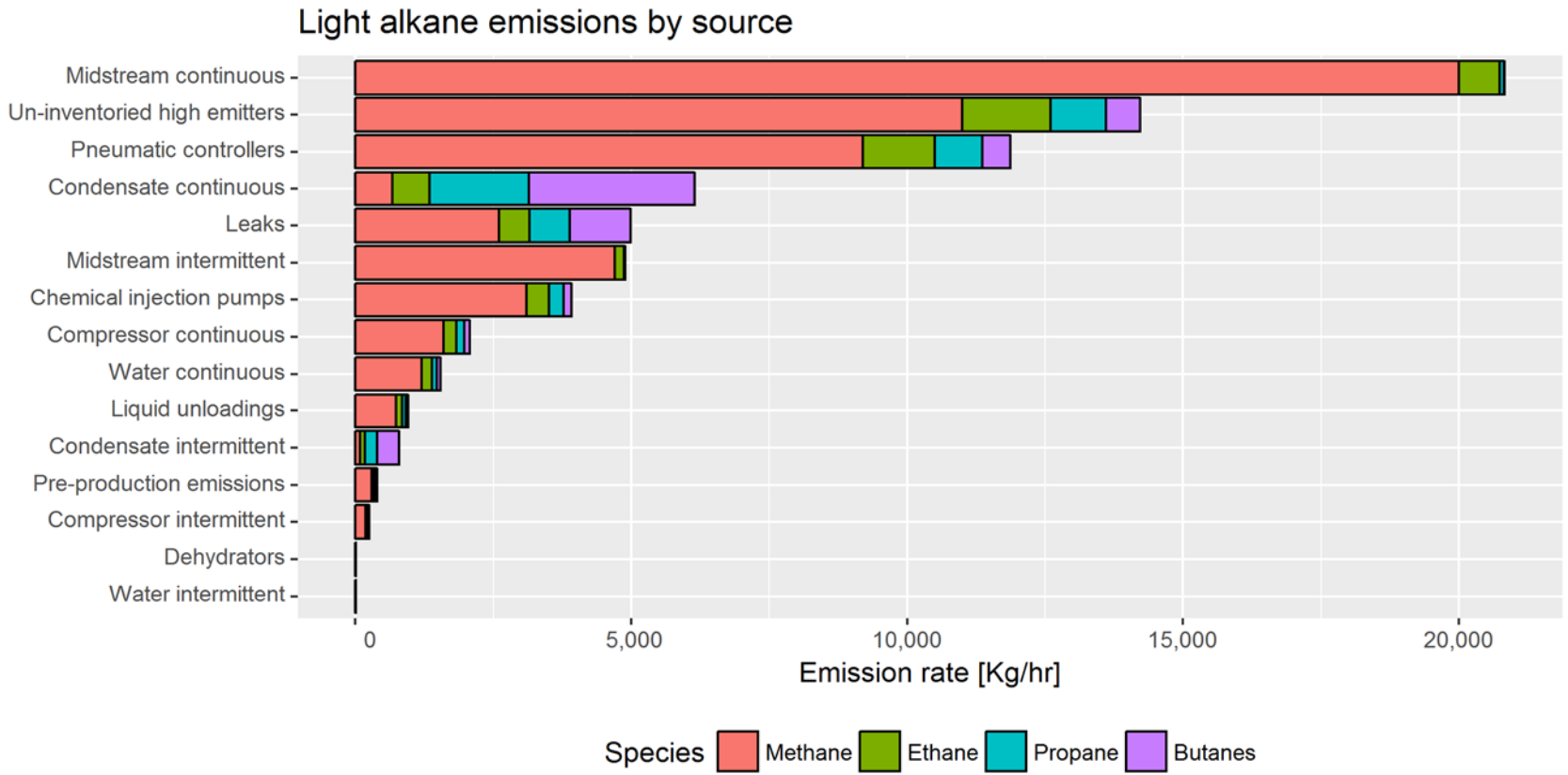
Emission Sources

"Un-inventoried high-emitters"

- Comparison of equipment based inventory with distribution of emission rates from drive-by measurements suggest ~11,000 kg/hr of methane emissions are not accounted for using equipment counts and emission factor distributions; these sources are referred to as un-inventoried high-emitters.
- Scenarios run with and without the additional 11,000 kg/hr.
  - Assumed 100 sites have the emissions, and they are randomly selected.

Emission Inventory

Emission Inventory



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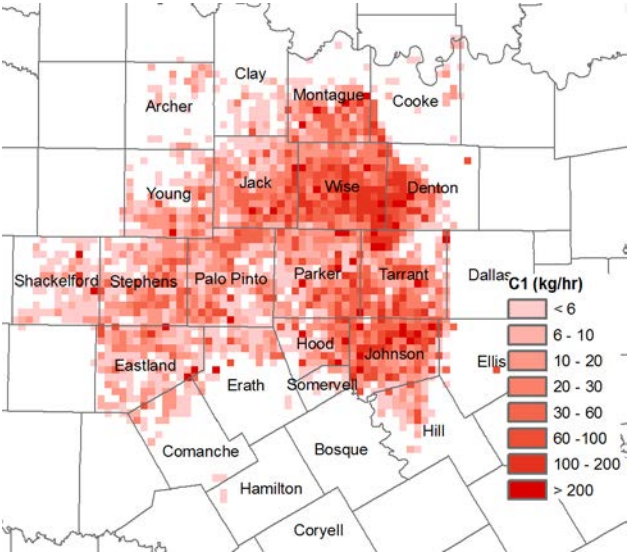
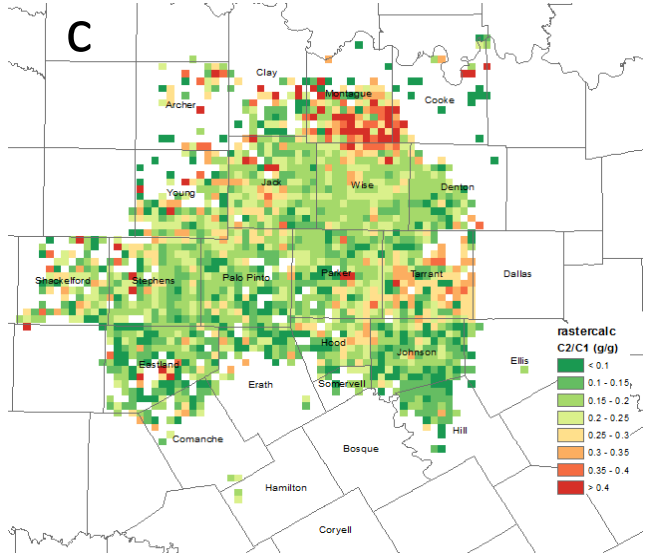
Intermittent vs. Continuous Emissions

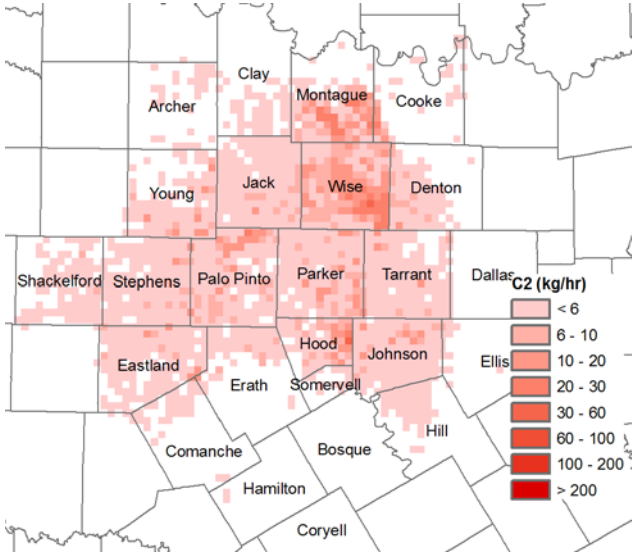
- Including un-inventoried high-emitters, intermittent sources account for ~30% of methane emitted (lower percentages for heavier alkanes)
- Some of these sources (e.g., compressor blowdowns, manual liquid unloadings) are expected to occur only during working hours
- Lower ethane to methane ratios expected for intermittent emissions than for continuous emissions since high flow rates of emissions will tend to be associated with produced gas, pipeline gas, or separator overhead compositions.

Emission Inventory

Spatial distribution of methane (a), ethane (b), and ethane to methane (c) emissions based on an average of 1,000 instances of hourly emissions.







Acknowledgements

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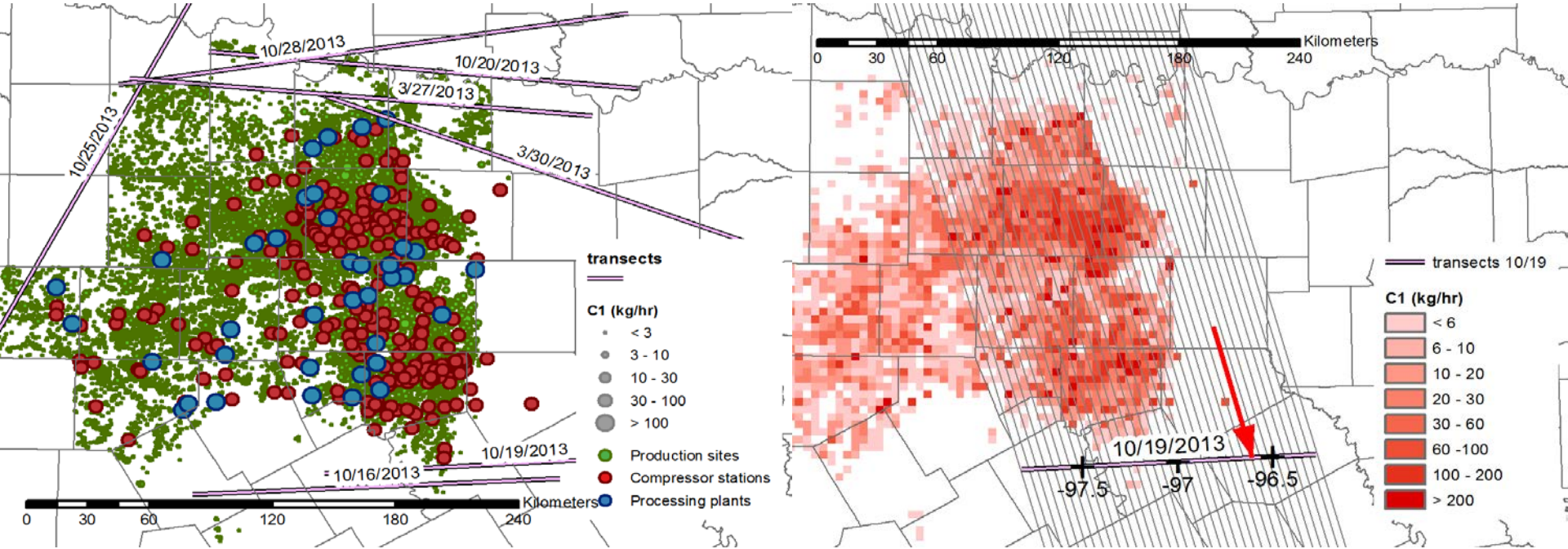

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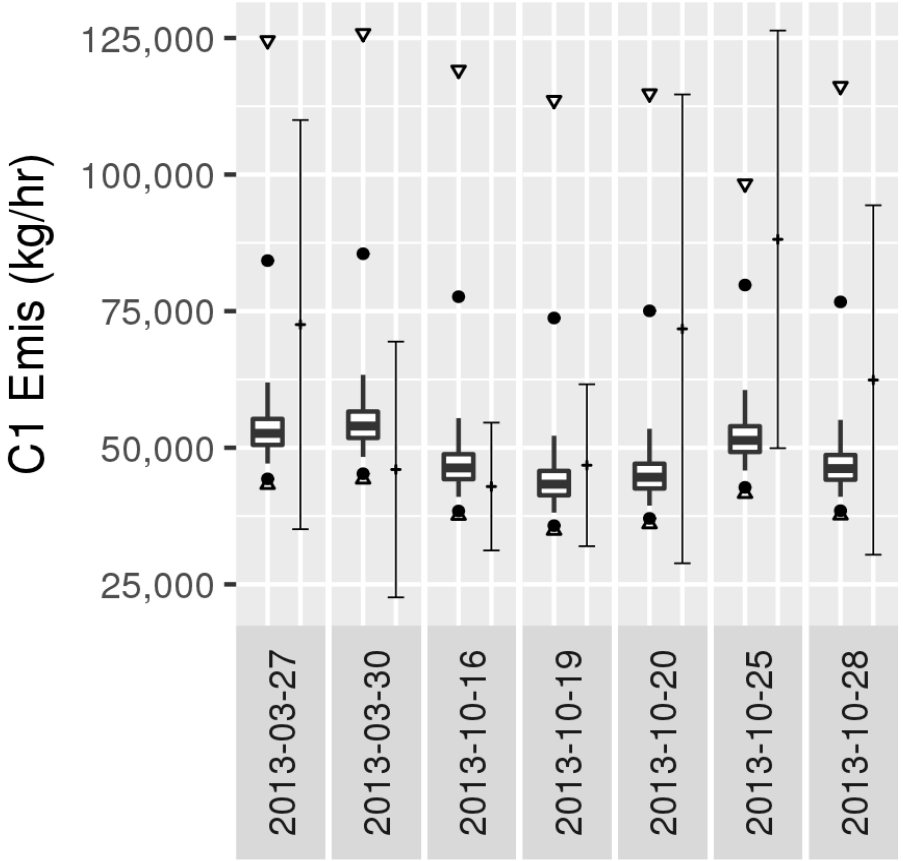
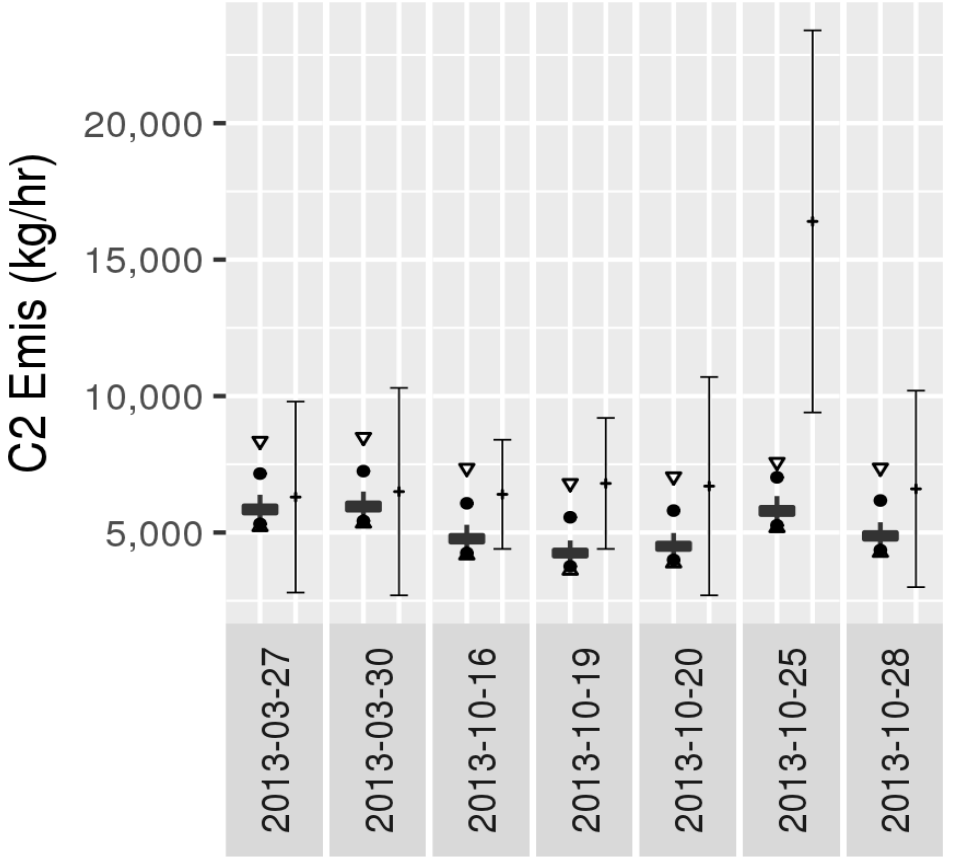
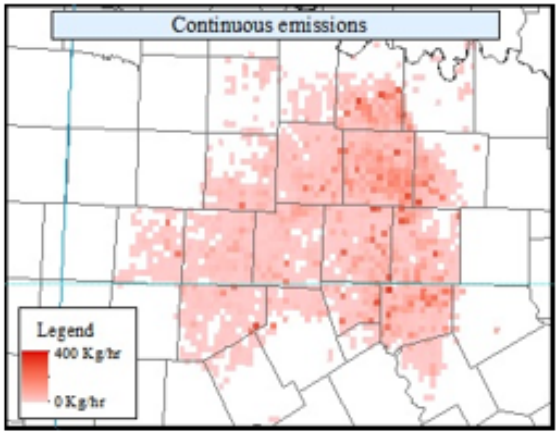
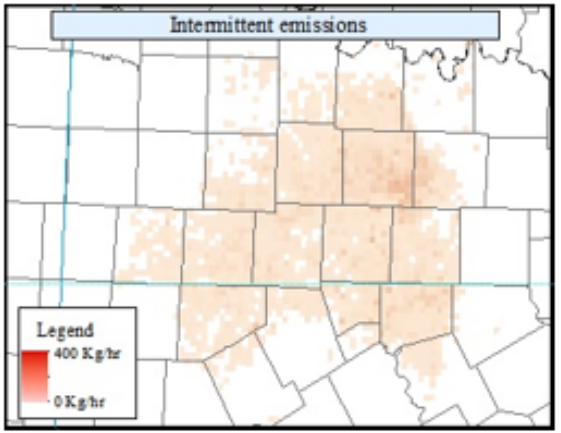
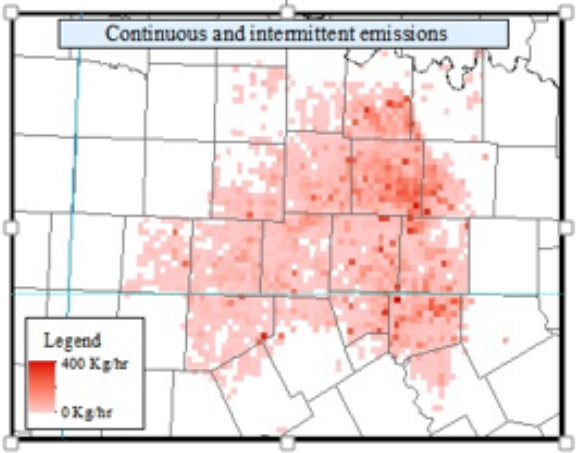
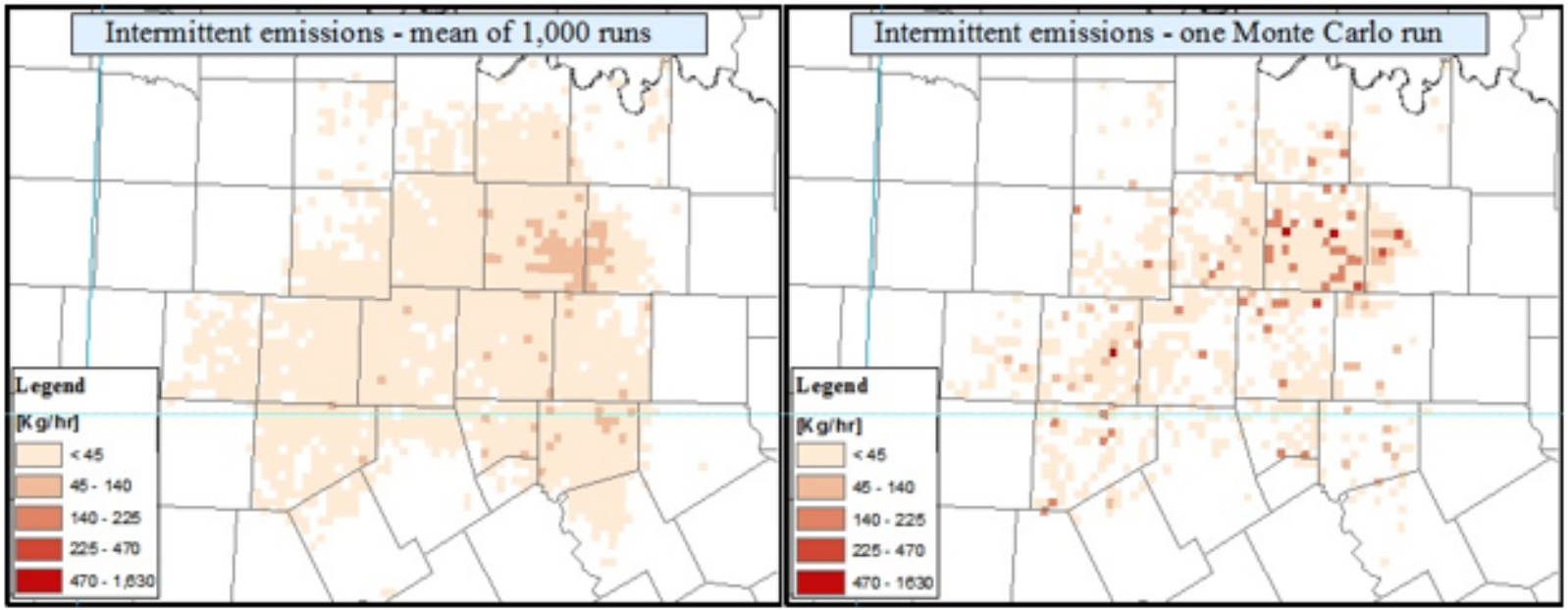

C1 Emis (kg/hr)
125,000
100,000
75,000
50,000
25,000
2013-03-27
2013-03-30
2013-10-16
2013-10-19
2013-10-20
2013-10-25
2013-10-28


C2 Emis (kg/hr)
20,000
15,000
10,000
5,000
2013-03-27
2013-03-30
2013-10-16
2013-10-19
2013-10-20
2013-10-25
2013-10-28


Continuous emissions
Legend
400 Kg/hr
0 Kg/hr


Intermittent emissions
Legend
400 Kg/hr
0 Kg/hr


Continuous and intermittent emissions
Legend
400 Kg/hr
0 Kg/hr


Intermittent emissions - mean of 1,000 runs
Legend
[Kg/hr]
< 45
45 - 140
140 - 225
225 - 470
470 - 1,630
Intermittent emissions - one Monte Carlo run
Legend
[Kg/hr]
< 45
45 - 140
140 - 225
225 - 470
470 - 1630