

Comparing top-down & bottom up estimates of oil & gas CH₄ emissions: A spatially-resolved emission inventory for the Barnett Shale Region

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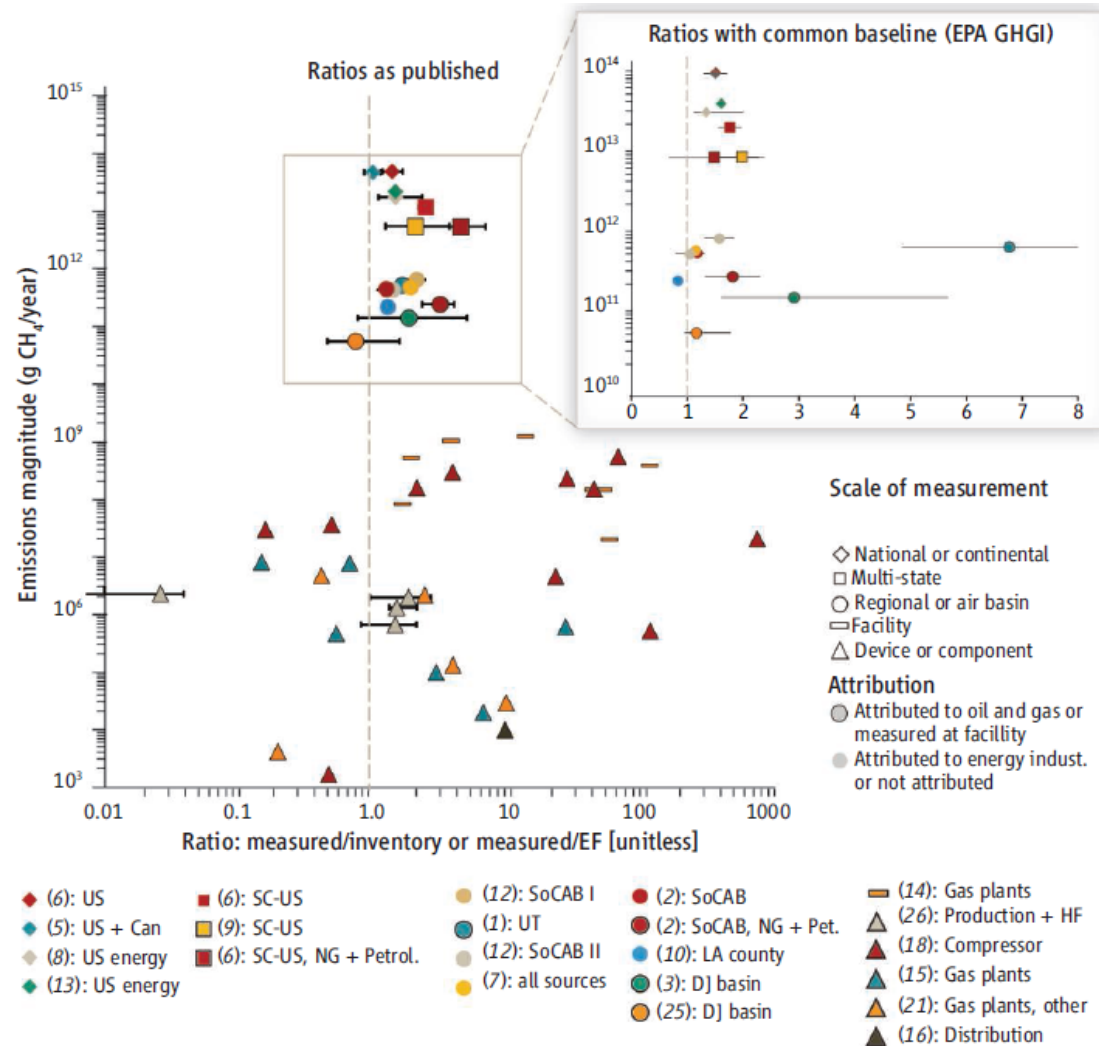
Top-Down vs. Bottom-Up

- Miller et al. 2013

- analysis of national atmospheric data
- top-down 1.5X higher than EPA GHG Inventory

- Brandt et al. 2014

- meta-analysis
- top-down 1.25 – 1.75X higher than EPA GHG Inventory



Different approaches have pros & cons

Top-Down

- Total emissions from large area
- Difficult to distinguish sources
- Typically from short time period

Bottom-Up

- Accurate data at the source
- Expensive to sample many sites
- Emission sources may be missed
- Sites may not be representative
- Activity data may be incomplete

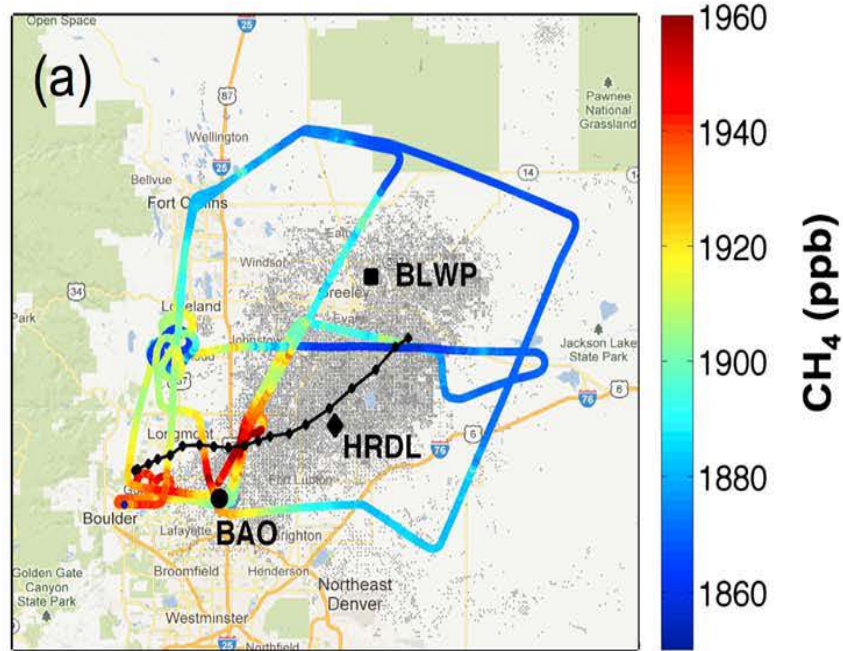


figure: Petron et al. 2014
photo credit: U. of Texas



Barnett Shale

October 16 – 30, 2013



EDF COORDINATED CAMPAIGN

PRODUCTION

GATHERING/PROCESSING

TRANSMISSION/STORAGE

LOCAL DISTRIBUTION

TRUCKS AND STATIONS

NOAA/CU/Michigan
Scientific Aviation/Penn State

Purdue University

Sander Geophysics

Princeton/
University of Texas - Dallas

Picarro/
Duke University

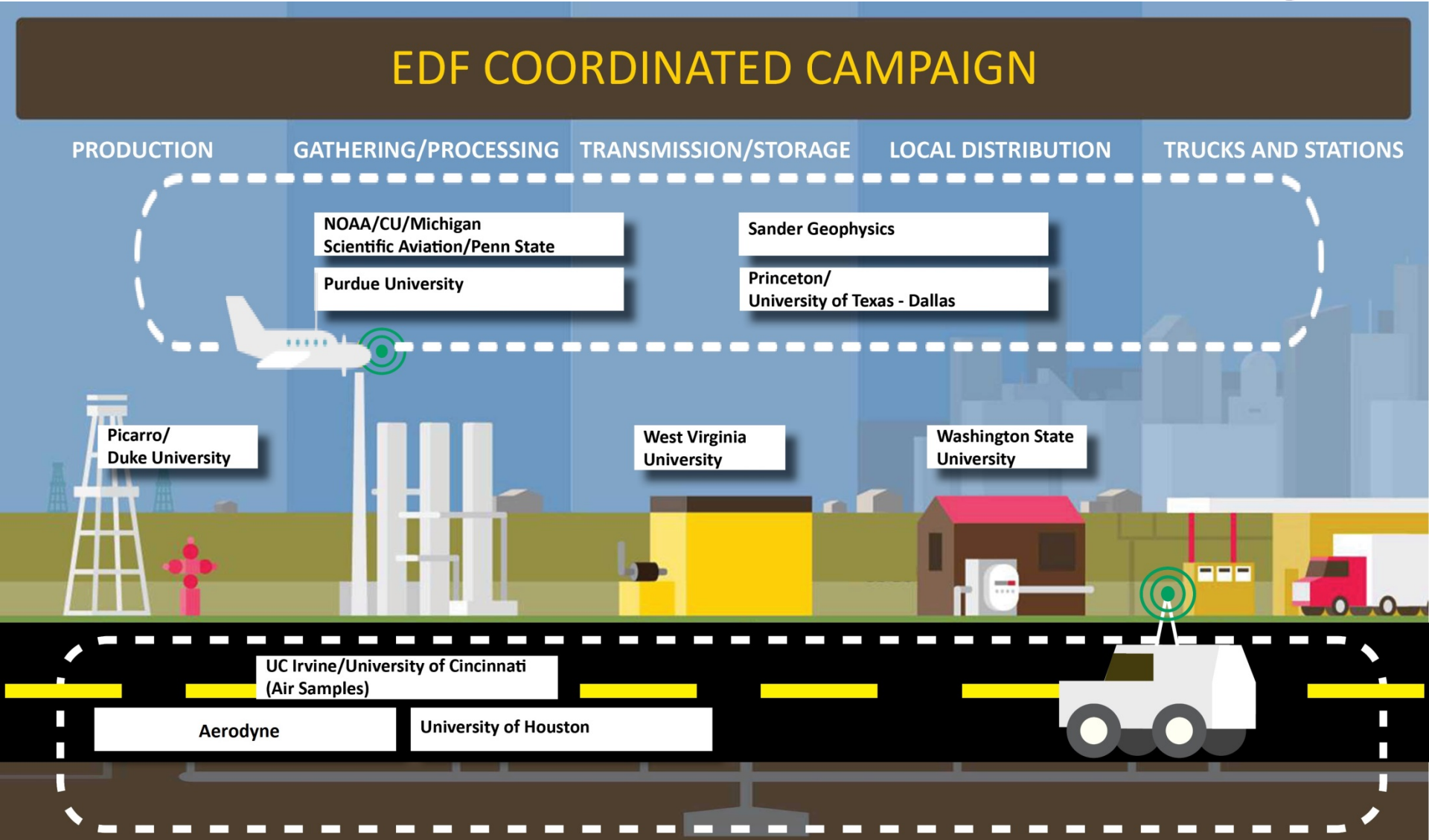
West Virginia
University

Washington State
University

UC Irvine/University of Cincinnati
(Air Samples)

Aerodyne

University of Houston



Barnett Campaign

- Bottom-up direct component measurements
 - West Virginia U. → 5 compressor stations
 - Washington State U. → 13 local distribution M&R stations
- Ground-based near-field measurements
 - Picarro → 186 well pads
 - U. Houston → 152 well pads, midstream facilities, & landfills
 - Aerodyne → 224 well pads, midstream facilities, & landfills



Barnett Campaign

- Aircraft-based near-field measurements
 - Purdue → 8 midstream facilities & landfills
 - Princeton/UT-Dallas (remote-control model aircraft) → repeat measurements of one compressor station
 - Sander Geophysics/Shell Global Solutions → locations & emission rate of sources in survey areas by Markov Chain Monte Carlo analysis
- Aircraft-based top-down regional measurements
 - NOAA/CU/Scientific Aviation/U. Michigan/Penn State → mass balance estimates on 8 days



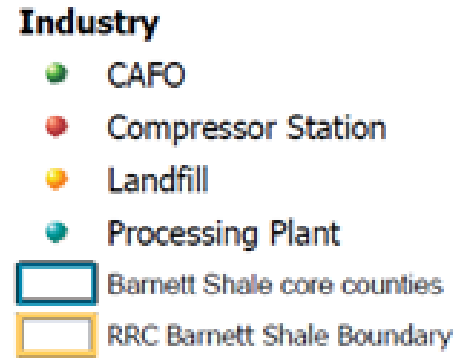
Barnett Campaign

- Source apportionment
 - UC-Irvine/U. Cincinnati → $\delta^{13}\text{C-CH}_4$, $\delta\text{D-CH}_4$ & hydrocarbon ratios of 119 source & background air samples
 - Picarro/Duke → $\delta^{13}\text{C-CH}_4$ of well pad plumes & background air
 - U. Michigan → aircraft mass balance of ethane and regional O&G C2:C1 to estimate fossil fraction
- Synthesis
 - **spatially-resolved methane emission inventory**
 - comparison of top-down & bottom-up estimates

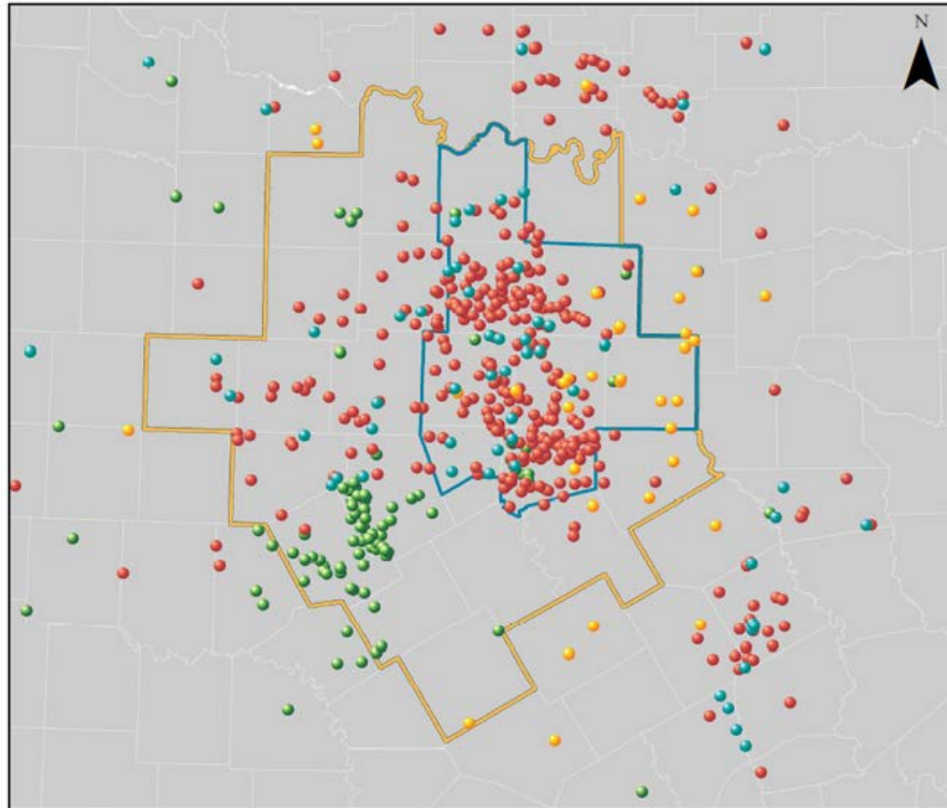


Spatially-Resolved Activity Factors

- EPA Greenhouse Gas Reporting Program
- EPA National Emissions Inventory
- TCEQ Barnett Shale Special Inventory (2009)
- TCEQ Permits
- Drillinginfo DI Desktop



Google Earth



O&G Facility Monte Carlo Simulations

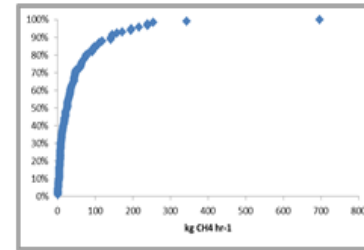
- Unbiased sample

- Production sites
 - Picarro = 186 well pads
- Midstream facilities
 - Mitchell et al. 2015
 - 100 compressor stations
 - 9 small & 16 large processing plants

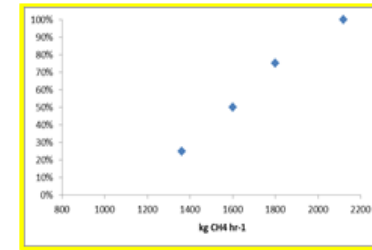
- Targeted sample (fat-tail)

- Production sites
 - U. Houston, Aerodyne
 - functional superemitters (paper by Zavala-Araiza)
- Midstream facilities
 - U. Houston, Aerodyne, Purdue
 - 9 stations & plants

Sampled Distribution



Fat-tail Site Distribution



probability = 1 - fat-tail frequency

[example = 0.98]



probability = fat-tail frequency

[example = 0.02]



random selection with replacement from one of two distributions for every site in 25 county region

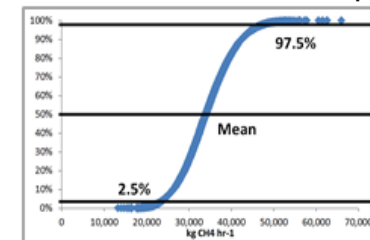
[example = 100 sites]

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100



10,000 iterations

Regional Emissions Distribution



Divide mean, 2.5th percentile, and 97.5th percentile regional emissions by number of sites in 25 county region (example = 100 sites)



95th confidence interval emission factor

[example = 343 (228 - 470) kg CH₄ hr⁻¹ site⁻¹]

[mean emission factor 25% higher from fat-tail sites]

Other O&G Sources

- Well completions

- location & production-based emissions (DI Desktop)

- Gathering & transmission pipelines

- location(DI Desktop) & EFs (EPA GHG Inventory)

- Local distribution

- 2013 pipeline miles (PHMSA) and M&R station counts (GHGRP) & EFs (Lamb et al. 2015)

Other Thermogenic Sources



- Industrial facilities
 - EPA GHG Reporting Program 2013 facility emissions
- Residential & Commercial End Use
 - TX 2013 gas delivered (EIA) prorated by population with assumed leak rate
- Gasoline & Diesel Vehicles
 - EPA 2011 NEI county-level emissions
- Natural gas vehicles
 - TX 2013 vehicle fuel delivered (EIA) prorated by vehicle miles traveled with assumed leak rate

Other Thermogenic Sources



- Abandoned wells

- location (DI Desktop) & emission factor (Kang et al. 2014)

- Geologic seepage

- global microseepage EF (Etiope & Klusman 2002)

Biogenic Sources

A photograph of a brown and white cow standing in a grassy field. The cow is facing the camera and is positioned in the center-right of the frame. The background consists of a line of trees and a clear sky. The image is slightly faded to allow text to be overlaid.

- Livestock

- CAFO point source (TCEQ) and county-level (NASS) 2013 cattle population & EFs (EPA GHG Inventory)

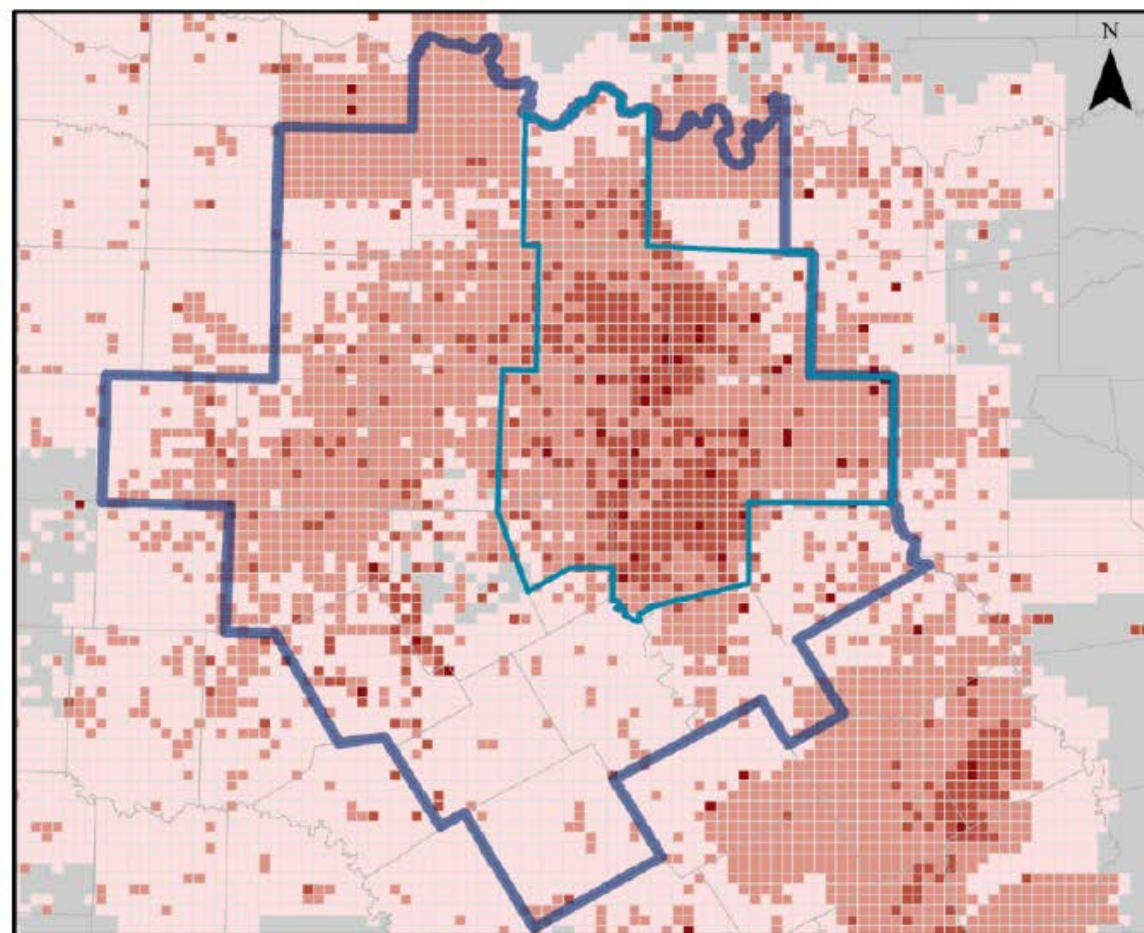
- Landfills

- GHGRP 2013 facility emissions adjusted up 18% for ~700 non-reporting landfills

- Wastewater treatment

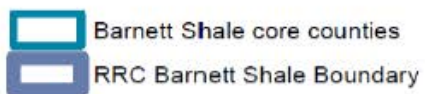
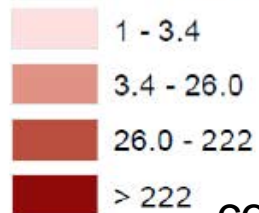
- National 2013 emissions (EPA GHG Inventory) prorated by population

Total Methane Emissions



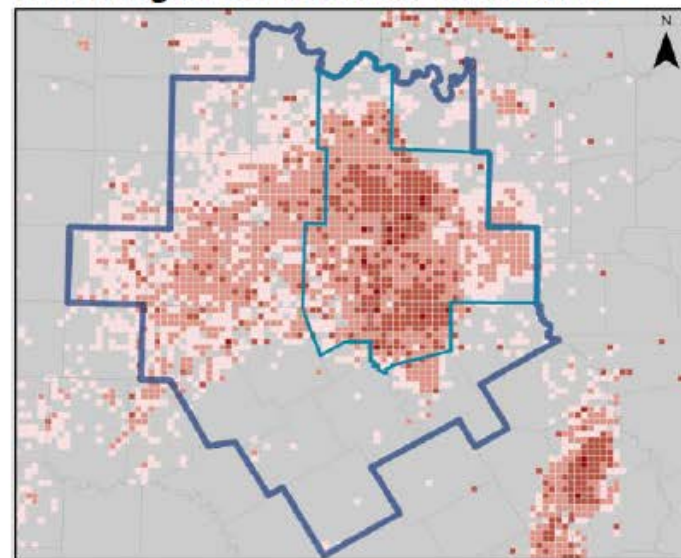
0 20 40 80 120 160
Kilometers

Methane Emissions (kg/h)



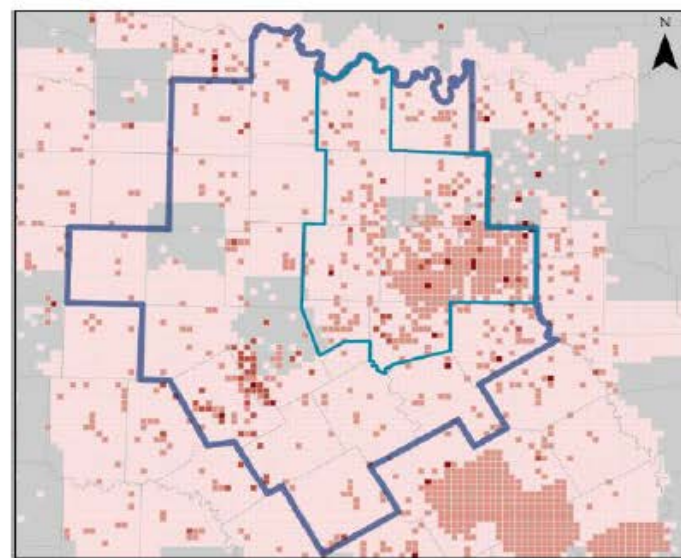
-confidential: do not cite or distribute-

Thermogenic Methane Emissions



0 20 40 80 120 160
Kilometers

Biogenic Methane Emissions



0 20 40 80 120 160
Kilometers

Barnett Campaign Status

- **12 papers submitted to *Environmental Science & Technology***
- **Published:**
 - Mobile Laboratory Observations of Methane Emissions in the Barnett (Yacovitch et al.)
 - <http://pubs.acs.org/doi/abs/10.1021/es506352j>
 - Measuring Emissions from Oil and Natural Gas Well Pads Using the Mobile Flux Plane Technique (Rella et al.)
 - <http://pubs.acs.org/doi/abs/10.1021/acs.est.5b00099>
- **Bottom-up**
 - Constructing a Spatially Resolved Methane Emission Inventory for the Barnett Shale Region (Lyon et al.)
 - Towards a Functional Definition of Methane Super-Emitters: Application to Natural Gas Production Sites (Zavala-Araiza et al.)
- **Top-Down**
 - Aircraft-based estimate of total methane emissions from the Barnett Shale region (Karion et al.)
 - Airborne ethane observations in the Barnett shale: Quantification of ethane flux and attribution of methane emissions (Smith et al.)
- **Synthesis**

Acknowledgements

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EDF STUDIES BY NATURAL GAS SUPPLY CHAIN SEGMENT

Production

Gathering/Processing

Transmission/Storage

Local Distribution

Trucks & Stations

- 
1. Barnett Coordinated Campaign
 2. NOAA Barnett
 3. NOAA Denver-Julesburg★

4. UT Phase 1★
5. UT Phase 2★
6. HARC/EPA★

7. CSU Study★

8. CSU Study★

9. WSU Multi-City★
10. Boston Study★
11. Indianapolis Study
12. Methane Mapping Project★
13. WVU Study

Other Studies:

14. Pilot Projects★

15. Gap Filling: Superemitters, Abandoned Wells

16. Project Synthesis

★ = results already public