Basin Methane Reconciliation Study

Research Leadership:
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Temporal Variability Largely Explains Difference in Top-down and Bottom-up Estimates of Methane Emissions from a Natural Gas Production Region

Proceedings of the National Academy of Sciences

https://energy.colostate.edu/basin-methane/

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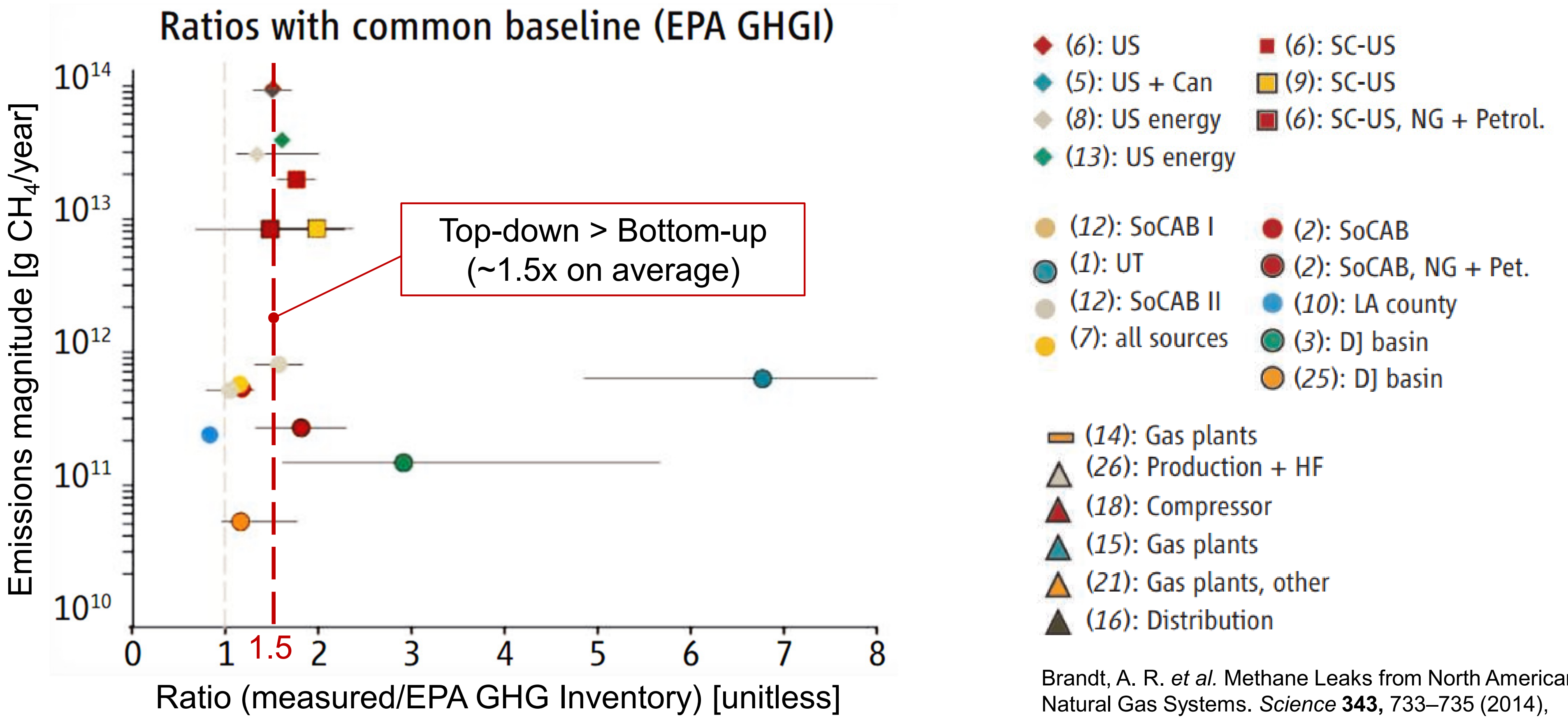
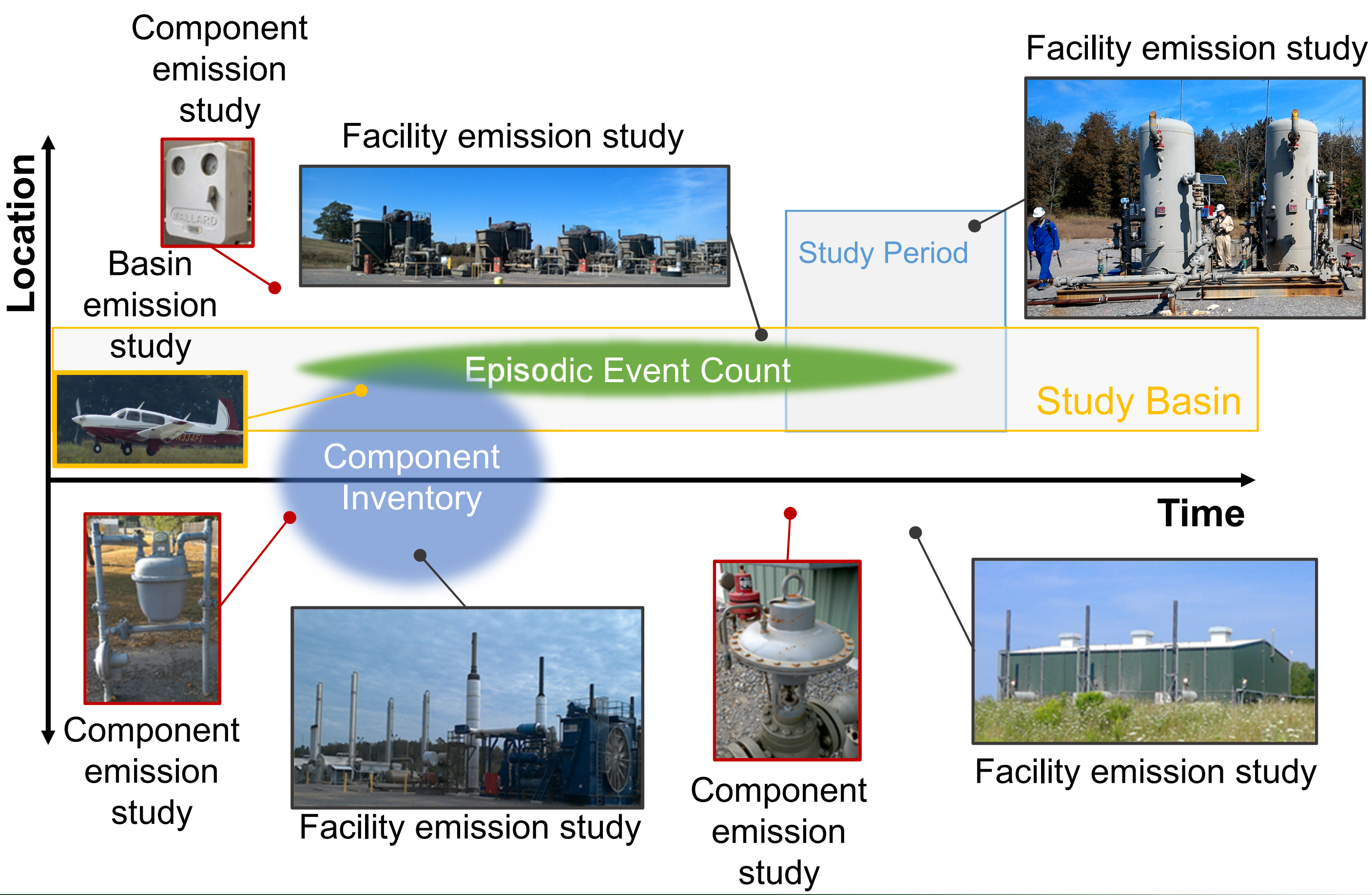
Past methane emission estimates differ



Brandt, A. R. *et al.* Methane Leaks from North American Natural Gas Systems. *Science* **343,** 733–735 (2014), DOI: 10.1126/science.1247045

What has been compared in past studies



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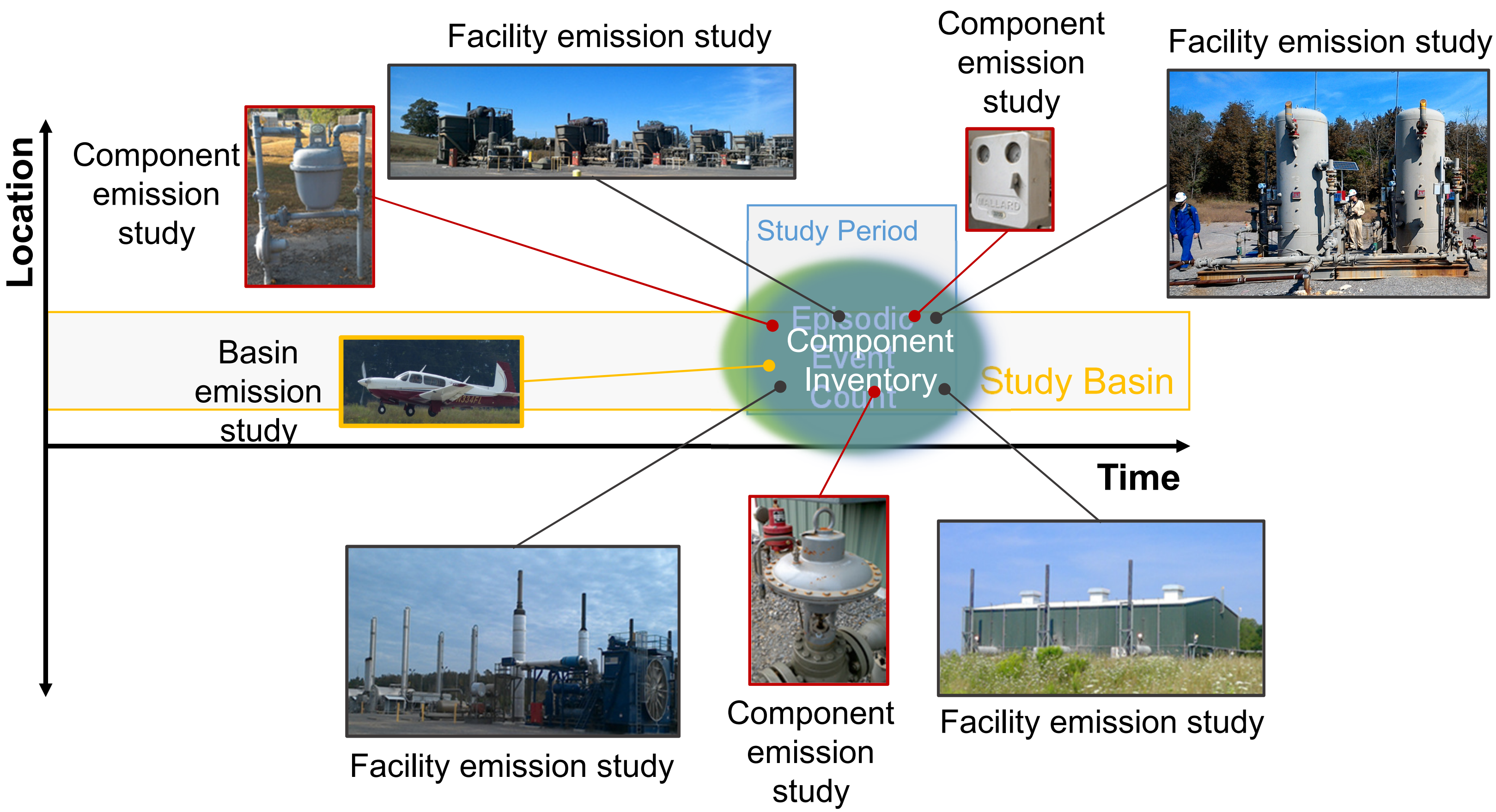
What was compared in this study



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Study overview

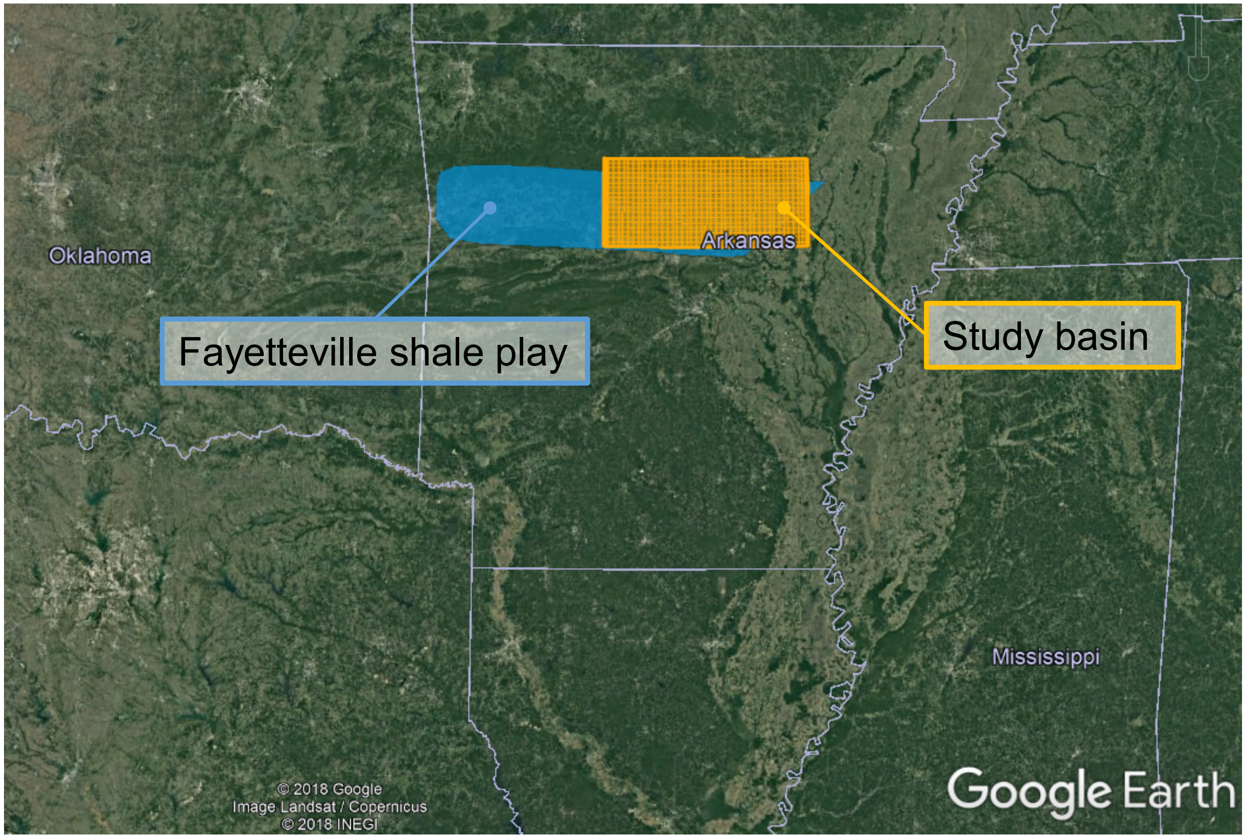
<u>Study Design:</u>

- Select **relatively isolated basin** with good partner representation
- **Measure most gas infrastructure** in the basin during same period as aircraft flights
- **Multiple measurement approaches** at facilities to understand true emissions
- Basin-specific, **high-resolution activity data**, facility & component counts, and episodic emission timing and location

<u>Study Luck:</u>

- **Steady wind** (north-to-south) for aircraft measurements

Study basin location



Majority of operations included in study

Production Facilities

- Site access: 82%
- Site data: 99%

Gathering Facilities

- Site access: 74%
- Site data: 100%

Transmission Facilities

- Site access/data 73%

Distribution

- Entire network in region

"Simple" operations

- Dry gas
- No storage
- No processing plants

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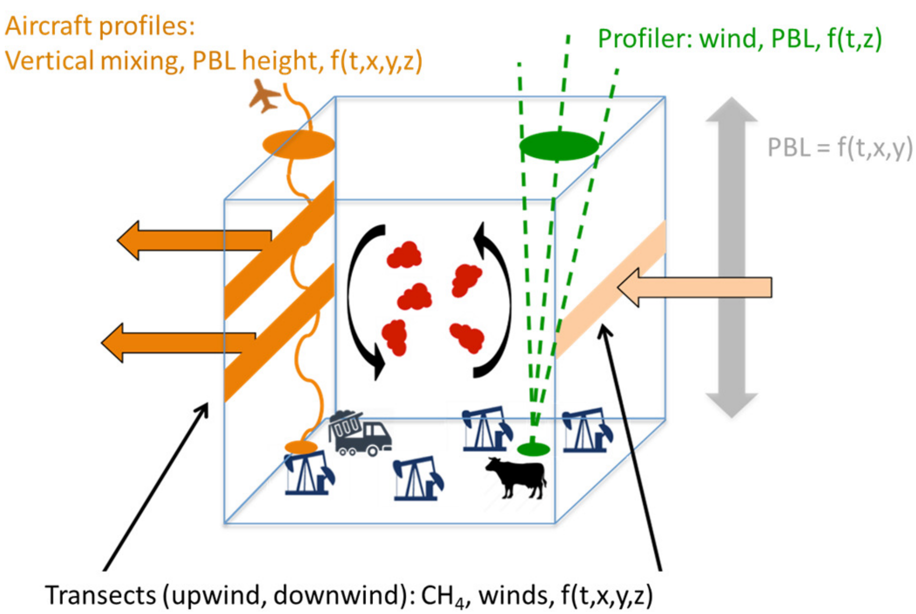
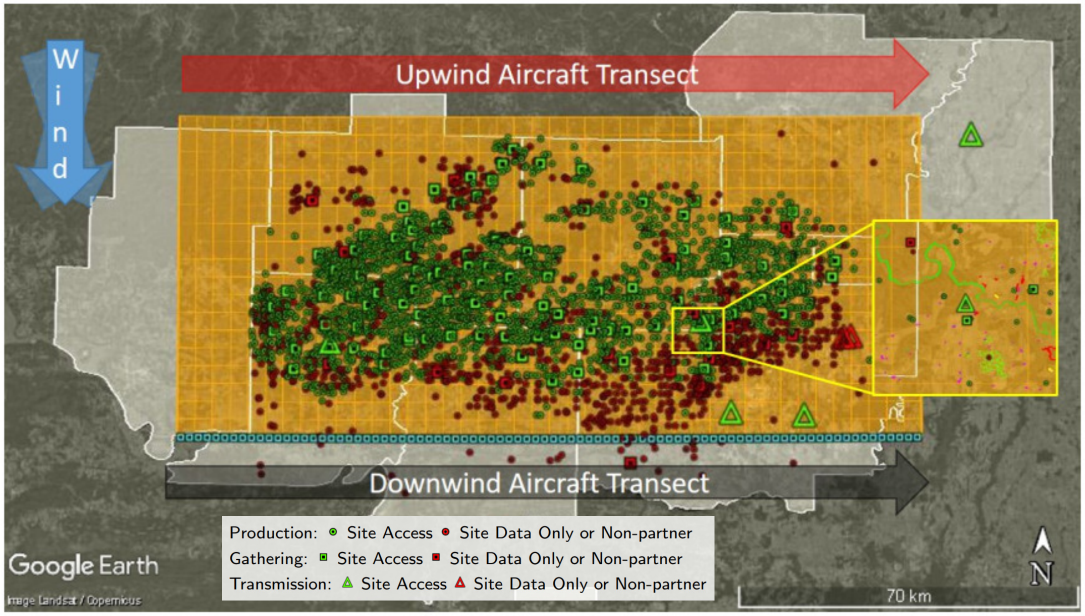
Compare methane emission estimates at basin-scale:
Top-down box model vs. spatiotemporal bottom-up model

Top-down



Bottom-up



Zimmerle, Daniel *et al.*, "Reconciling Top-down and Bottom-up Methane Emission Estimates from Onshore Oil and Gas Development in Multiple Basins: Report on Fayetteville Shale Study" (Colorado School of Mines, Golden, CO, 2016).

The Bottom-Up Estimate: Measurements & Sub-models

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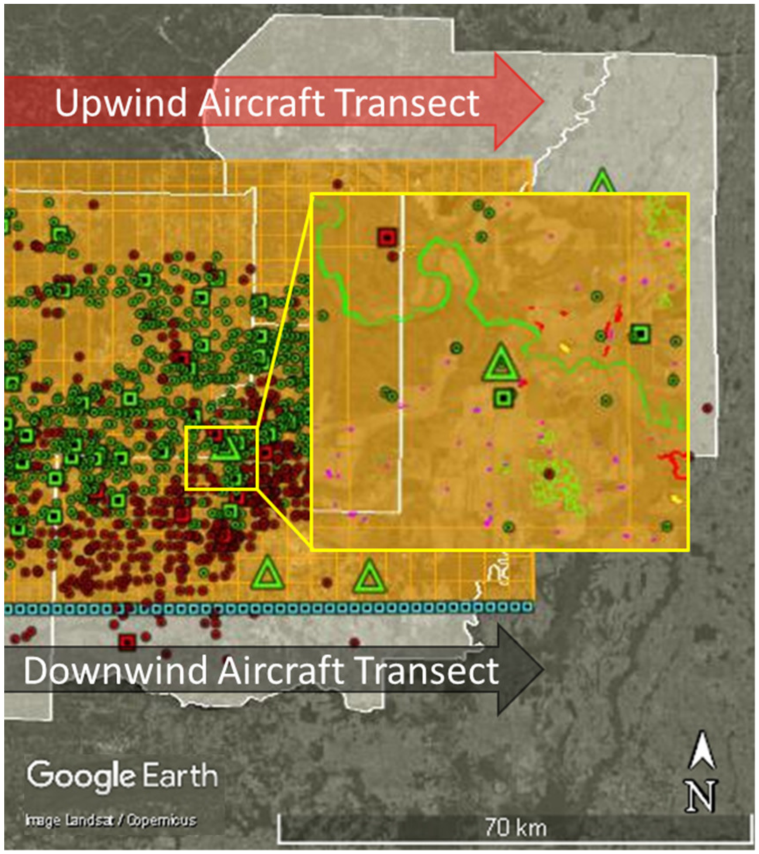
Inputs to bottom-up model



Activity Data:

- Production Facilities
  - Unloading events
- Gathering Facilities
  - Engine Operations
- Transmission Facilities
- Gathering Pipelines
- Distribution
- Livestock
- Geologic Seeps
- Wetlands
- Landfills
- Rice Cultivation

Emission Factors:

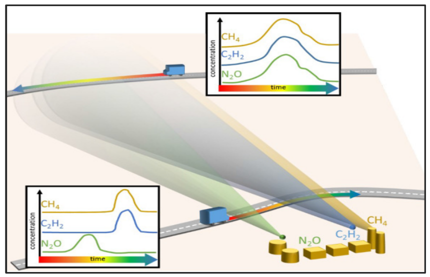
- Production Facilities
  - 261 On-site
  - 50 OTM33A
  - 17 Tracer
- Gathering Facilities
  - 33 On-site
  - 30 Tracer
  - 11 Aircraft
- Transmission Facilities
  - 4 Tracer
- Gathering Pipelines
  - 96 km
- Distribution
  - Entire Leak list
- Non O&G from Literature

Note: No gas processing plants, gas storage facilities, or major chemical plants in the study area

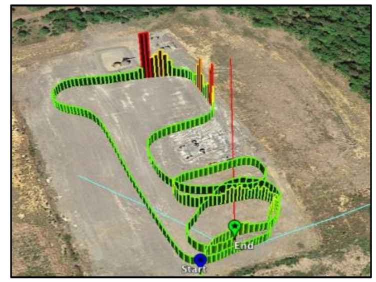
Quantifying BU emissions

Direct component measurements

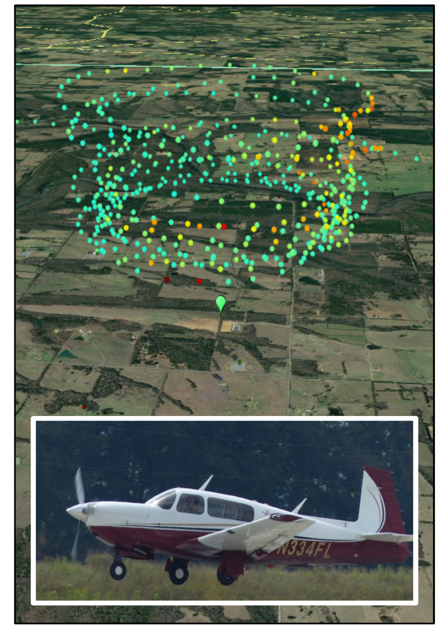
Tracer flux



OTM33A



Aircraft facility estimates



Paired In Various Combinations

Bottom-Up Field Campaign & Analysis

- Acquired extensive activity data for all of the natural gas infrastructure in study area:
  - Activity data from ≈98% of natural gas facilities in study area
  - Production and gathering operations were the largest sources
  - Small contribution from transmission compressor stations
  - Even smaller contributions from gathering pipelines and natural gas distribution
- Made paired measurements at
  - Gathering compressor stations
  - Well pads

Production Facility Measurements

- 2430 well pads in study area
- Successfully measured emissions at 262 well pads
  - 1 manual unloading
    - Tracer meas: ≈800 kg/h

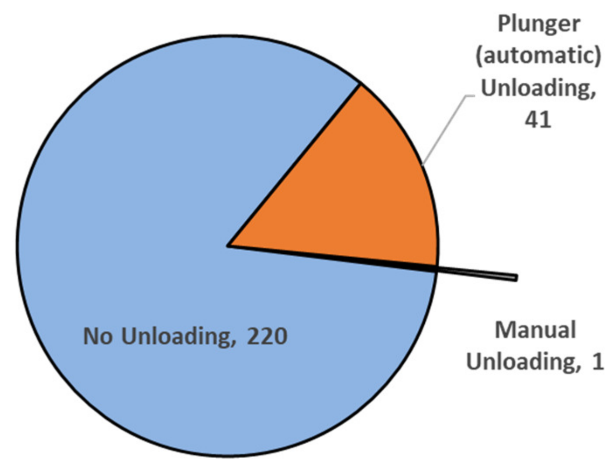
  Typically daytime only

  - 41 pads had automatic unloadings:
    - Flow: est. 8-350 kg/h
    - Duration: 0.1- 1.8 hours
    - Frequency: 3-36,500 per year

  Automated control operates 24/7

  - Other emissions:
    - 0-107 kg/h
    - Includes pneumatic controllers

  Unknown duration, assumed continuous



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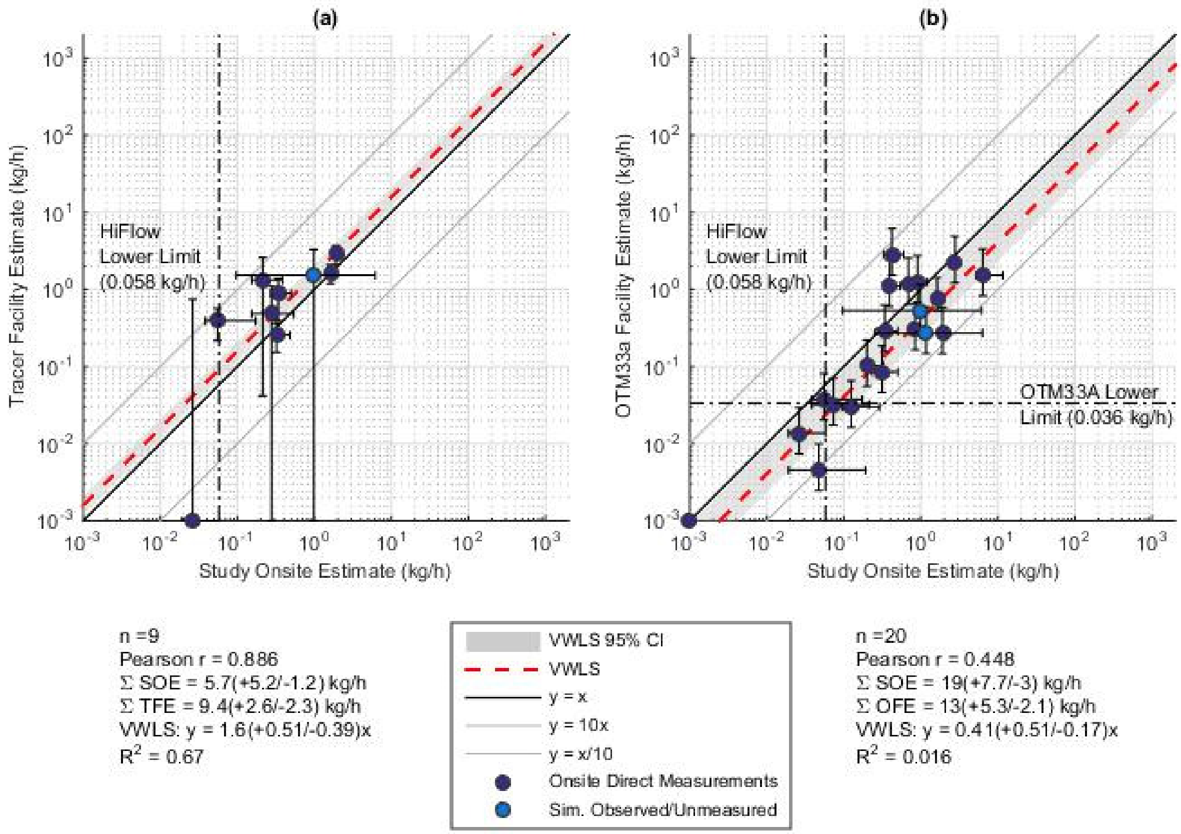
Production - Method Comparison

- Paired methods:
  - Onsite estimates – measured + simulated
- OTM 33a
  - Emissions ≈60% lower than onsite
  - R^2 of 0.02
- Tracer
  - Emissions ≈60% higher than onsite
  - R^2 of 0.7



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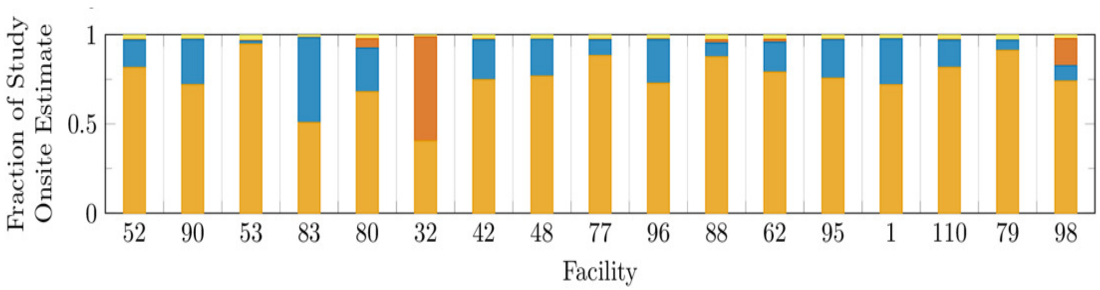
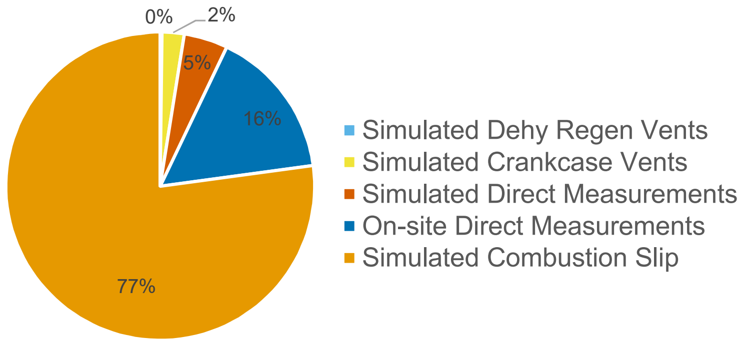
Gathering Compressor Station Emissions



(a) Emission source fraction - individual gathering facilities



(b) Emission source fraction - all gathering facilities

- Most emissions at facilities operating normally are from "combustion slip"
  - *Unburned methane in exhaust of compressor engines*
  - Data from recent stack testing performed by partners

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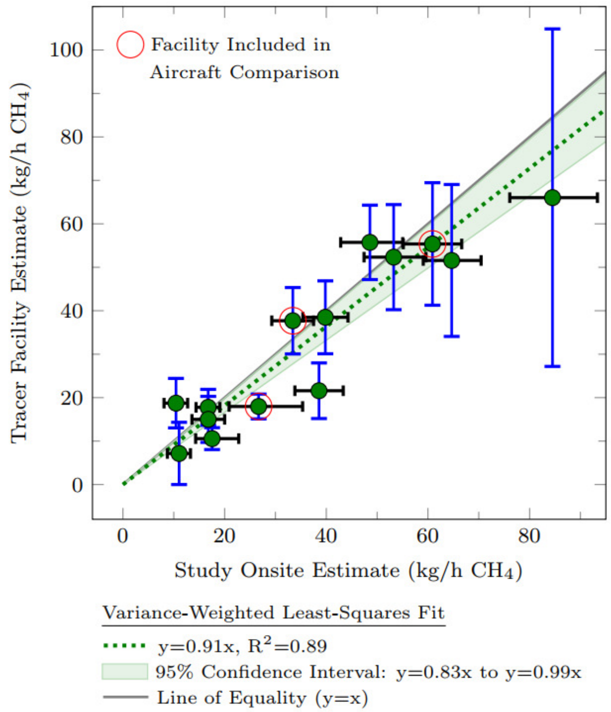
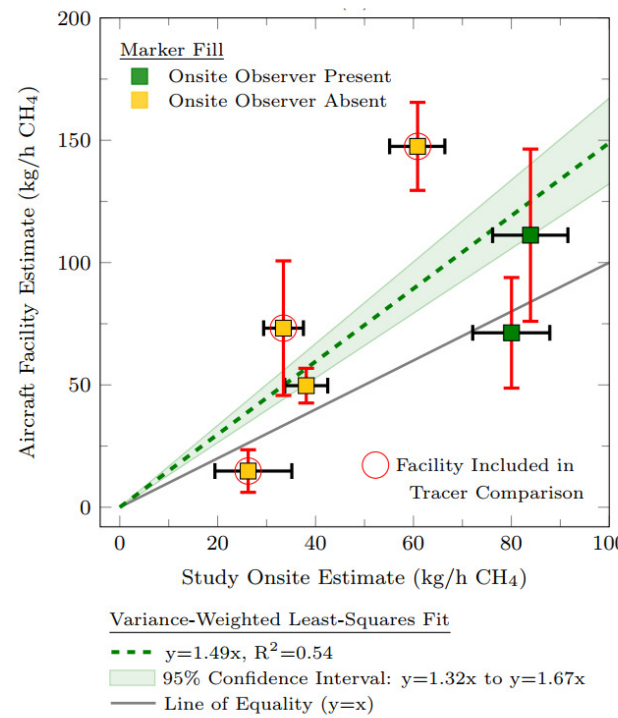
Gathering - Method Comparison

- Paired methods:
  - Onsite estimates – measured + simulated
- Tracer
  - Similar to Onsite
  - R^2 of 0.9
- Aircraft
  - Emissions ≈50% higher than onsite
  - R^2 of 0.5
    - Small sample





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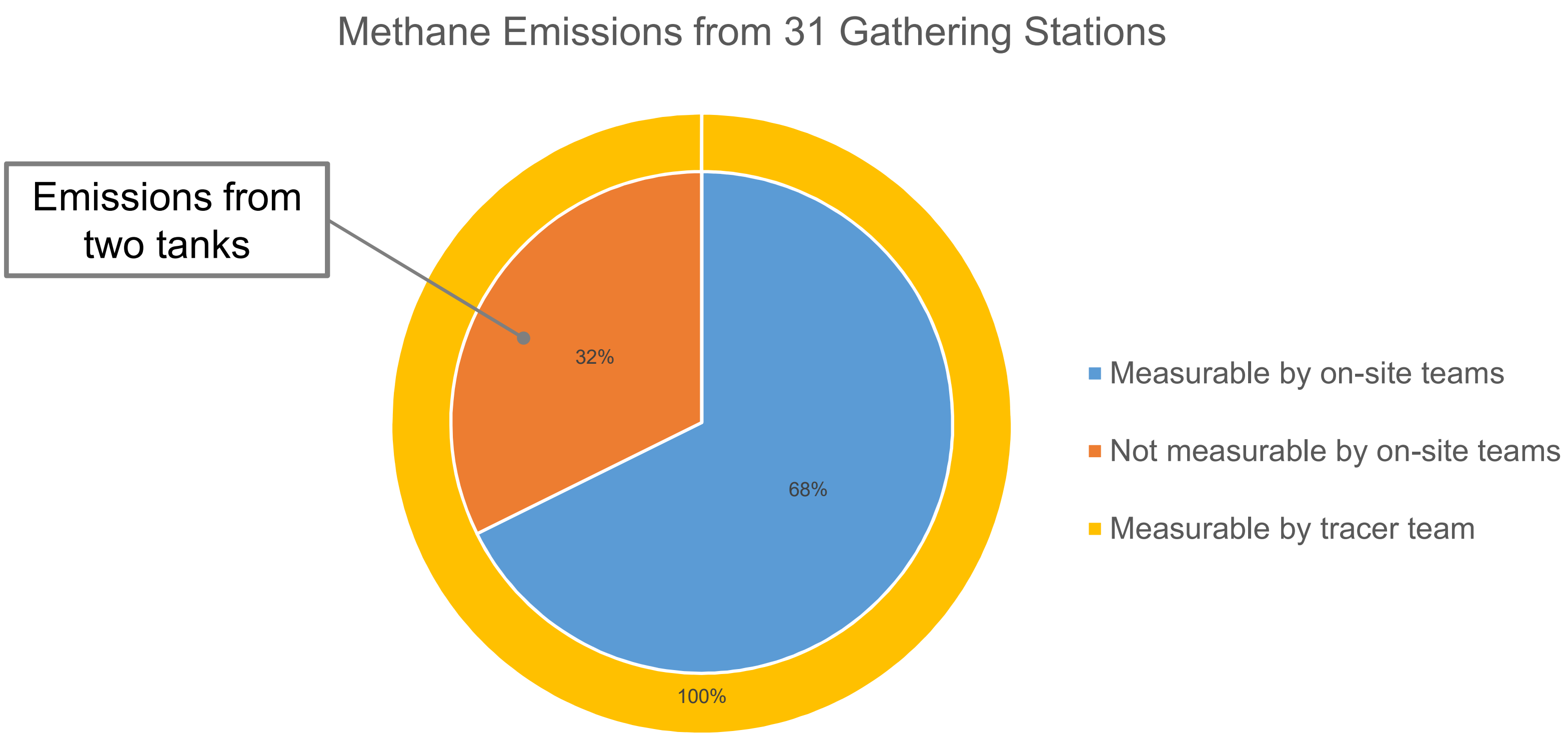
Downwind methods capture large emitters (that on-site teams sometimes can't)



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Gathering Pipelines

Sampled 96 km of gathering pipeline

- 4,680 km in study area
- Measurements by GHD
- Vehicle-based leak detection

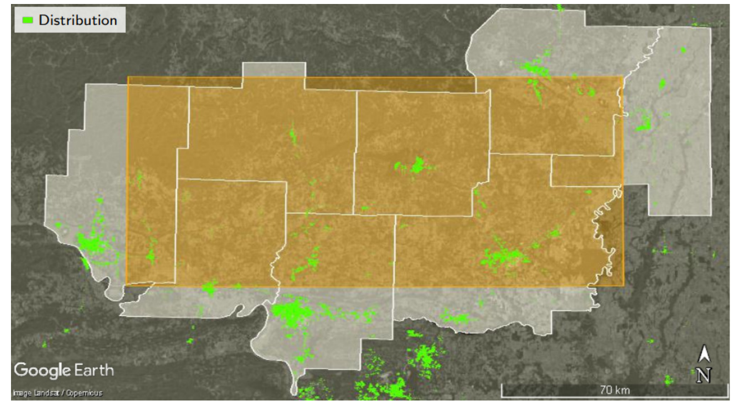
Leaks:

- 1 pipeline leak = >95% of all emissions
- 34 above-ground leaks

No new emission factors

- Existing GHGRP EF agree with data better than newer distribution data

Distribution



Distribution sector infrastructure is concentrated in urban and suburban regions.

One study partner serves the entire study area (orange shaded region).

Measured

- Nearly all emissions from “leak list” of distribution company
- 28 city gate stations
- 100 regulators

Emissions are small relative to other natural gas sectors

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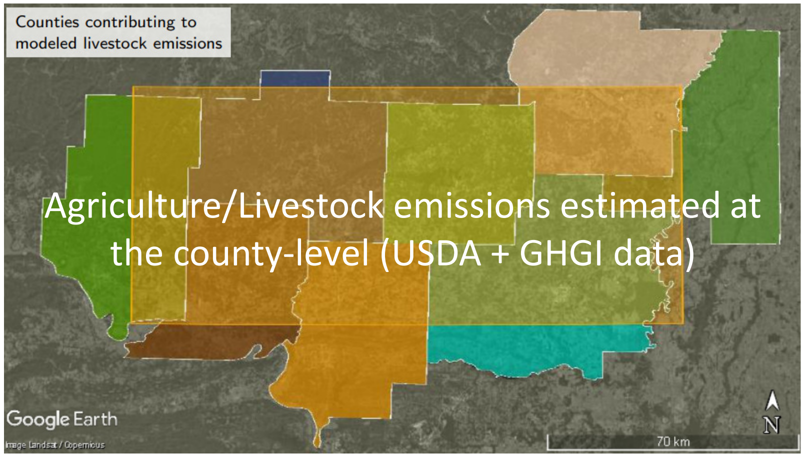
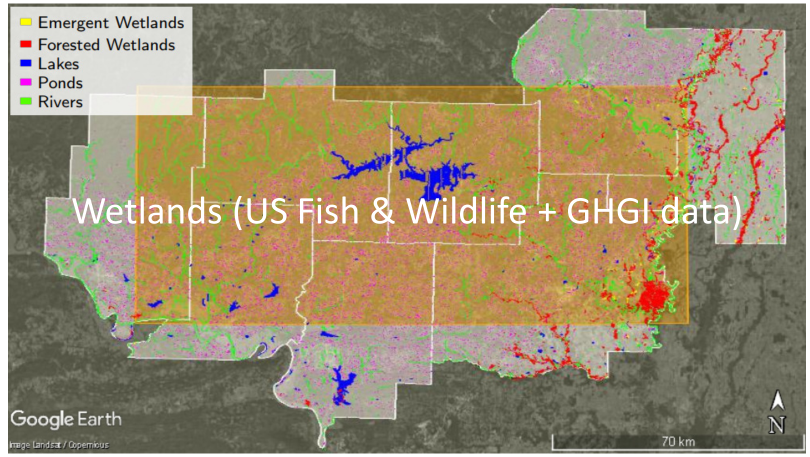
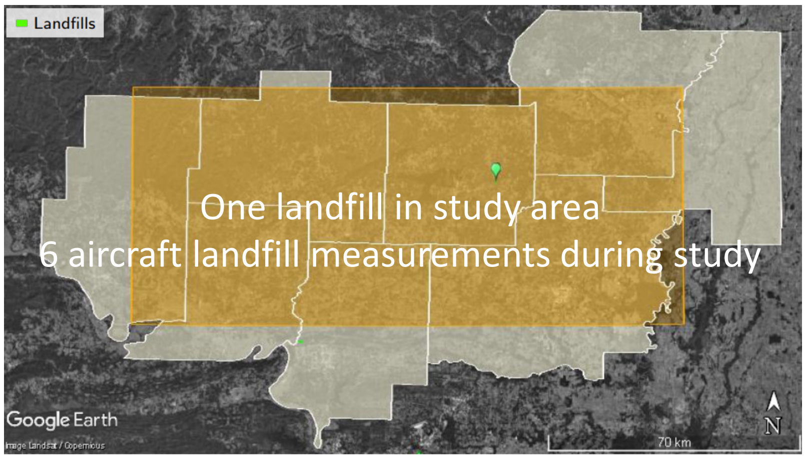
Non O&G Methane Emission Sources







- Others …
  - Geologic seeps
  - Wastewater treatment – municipal and septic systems
  - Other power plants (1 in study area)

Accounting for every source possible

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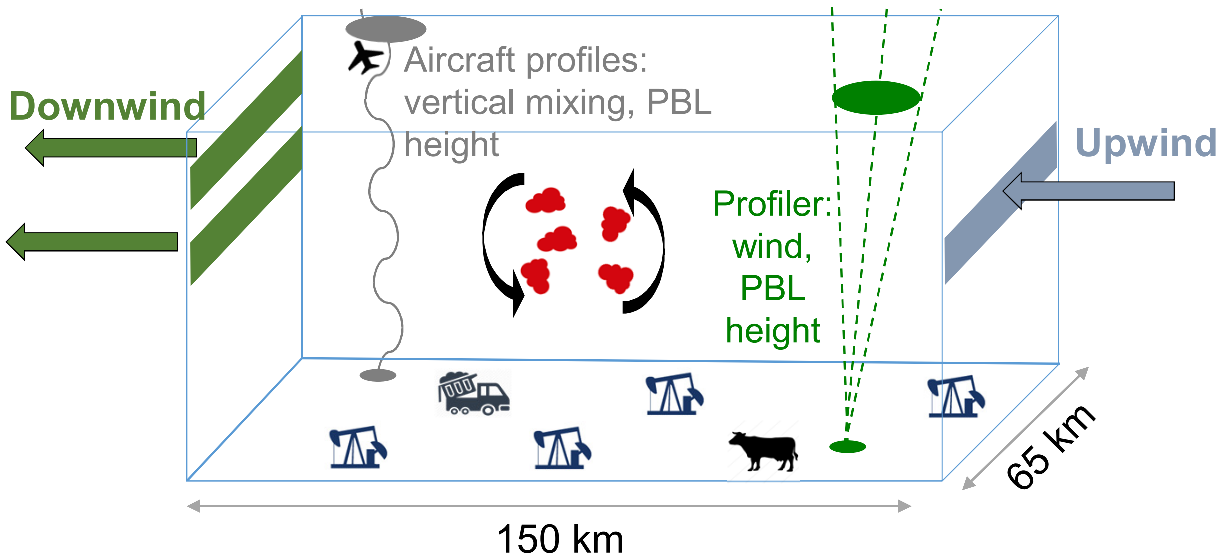
Top-Down Measurements

Aircraft mass balance method

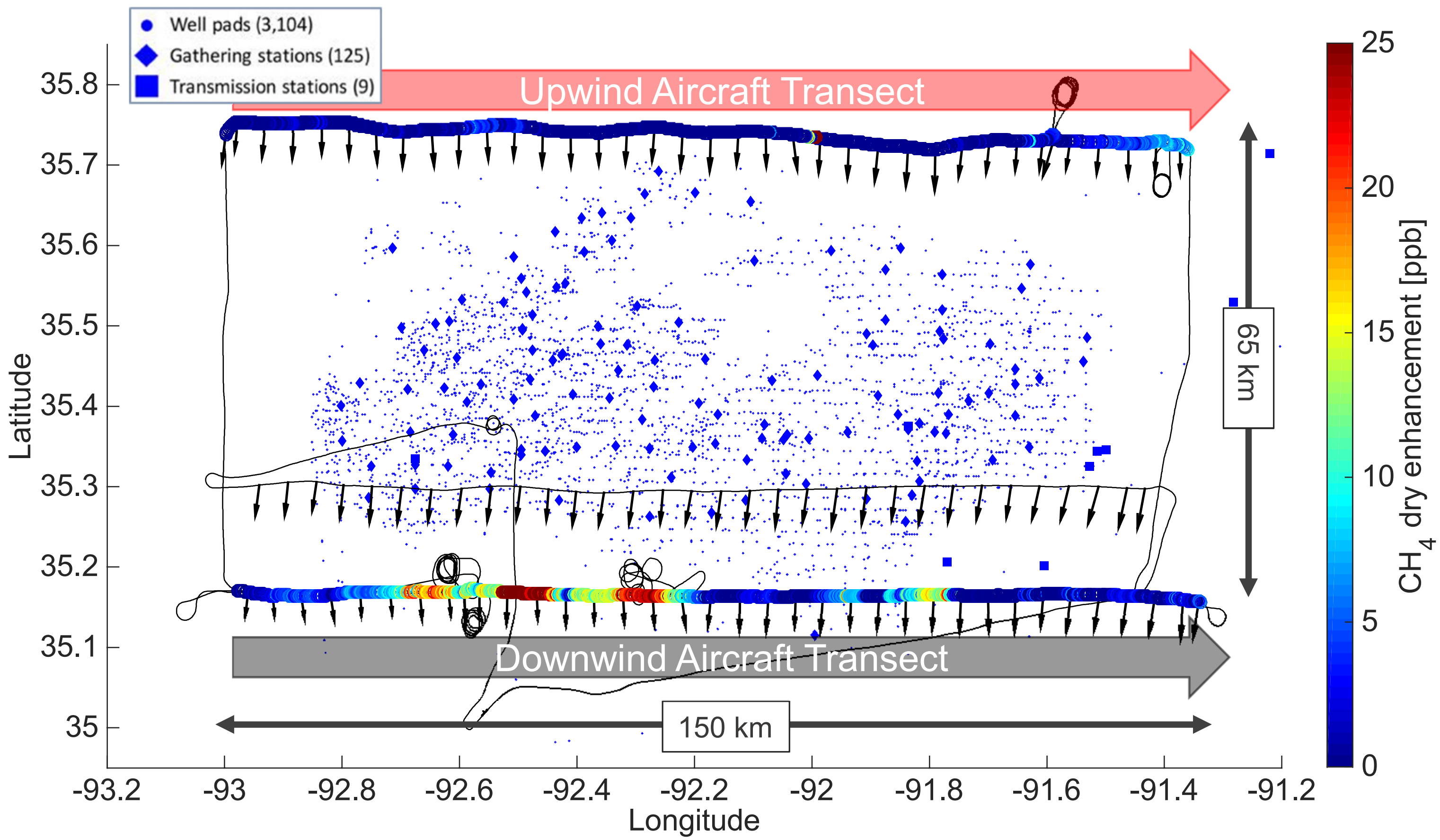
- 15 flights in 23 days (Sep/Oct)
- 2 flights (Oct 1 & 2) with ideal meteorological conditions for aircraft mass balance



Remaining flights:

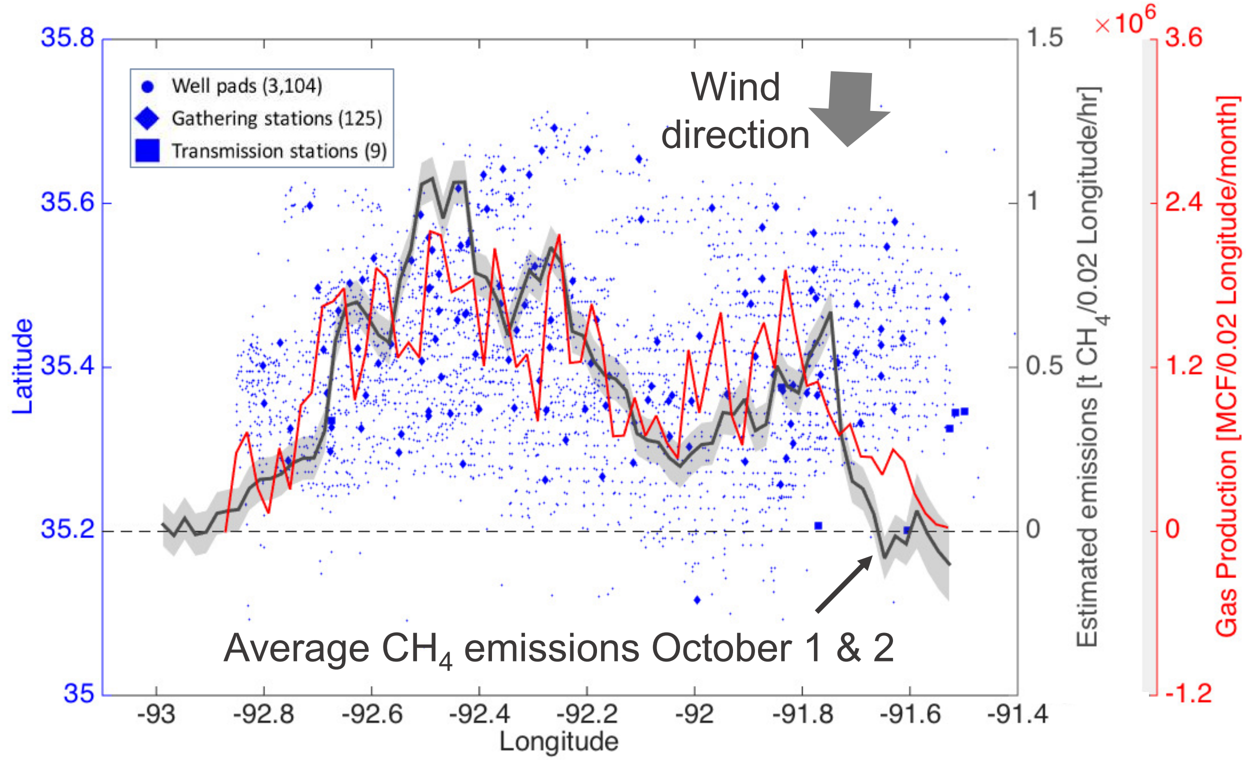
- Identify larger emitting sub-regions incl. repeats to check consistency
- Sample ethane:methane ratios for source attribution
- Quantify CH_4 emissions from individual facilities

October 1, 2015 flight overview



First spatially-resolved aircraft-based CH_4 emission estimates for a basin

- Strong spatial correlation with well count
  - $R^2 = 0.81$ for ~2 km wide longitudinal bins
- Also strong spatial correlation with natural gas production
  - $R^2 = 0.75$



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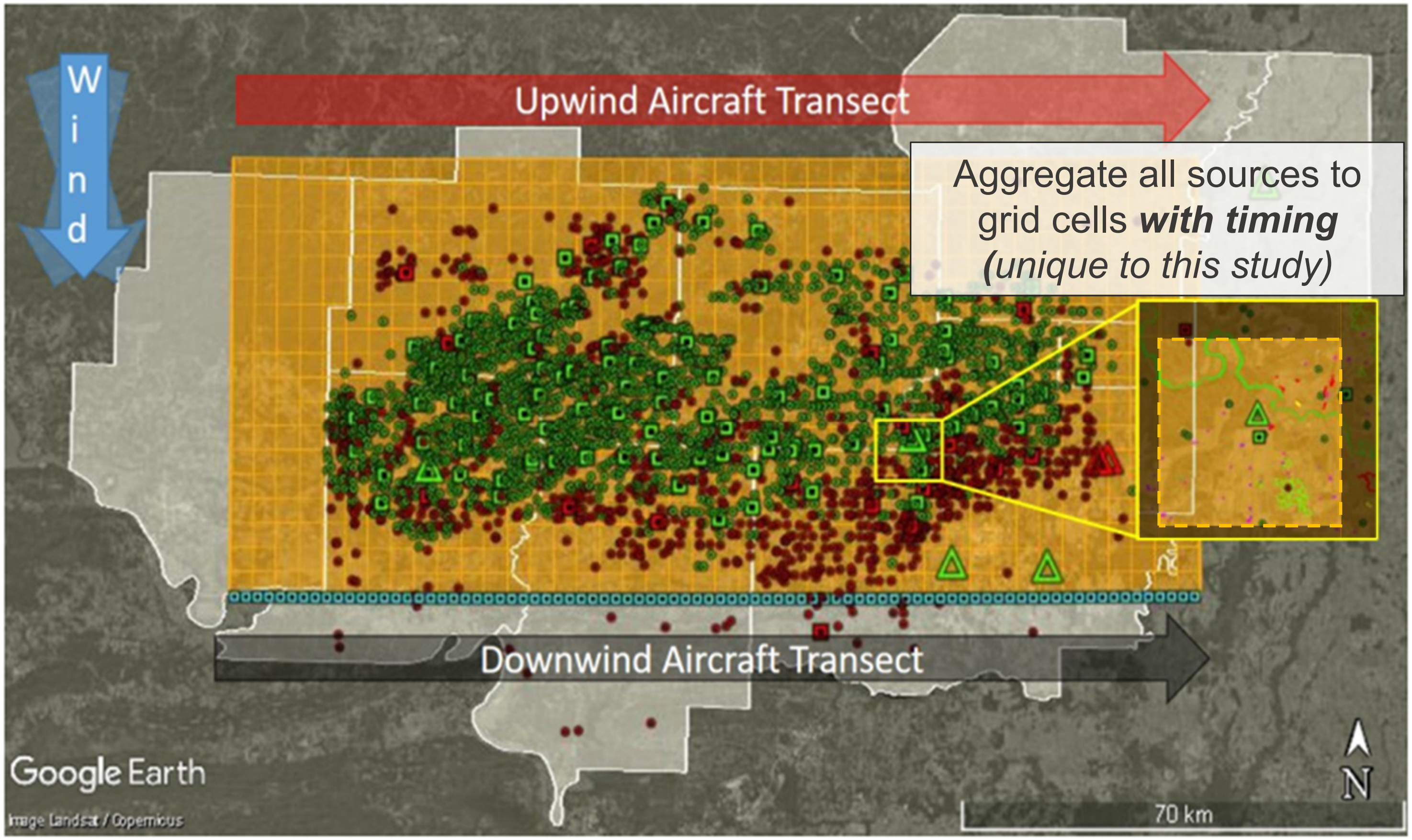
Comparing Top-Down to Bottom-Up

Study basin total emissions



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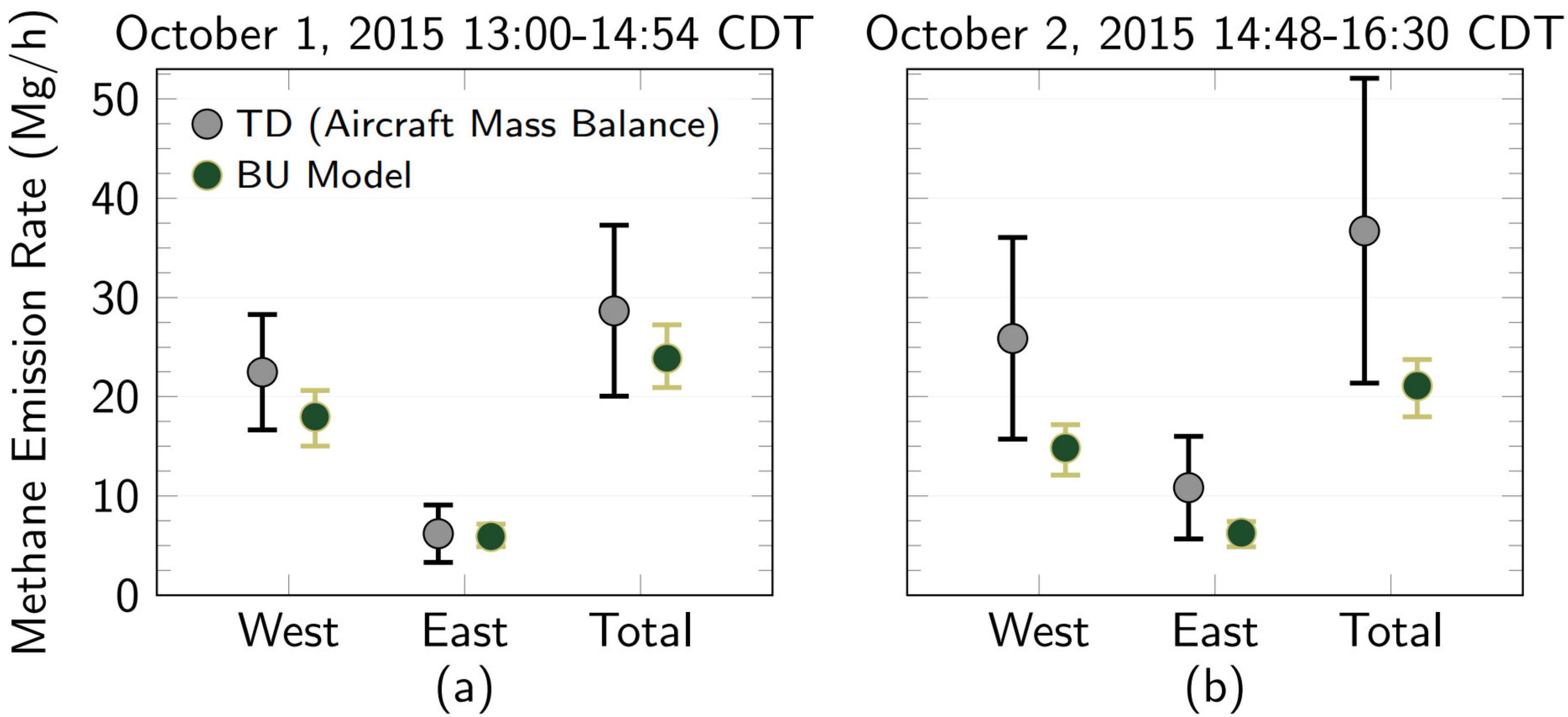
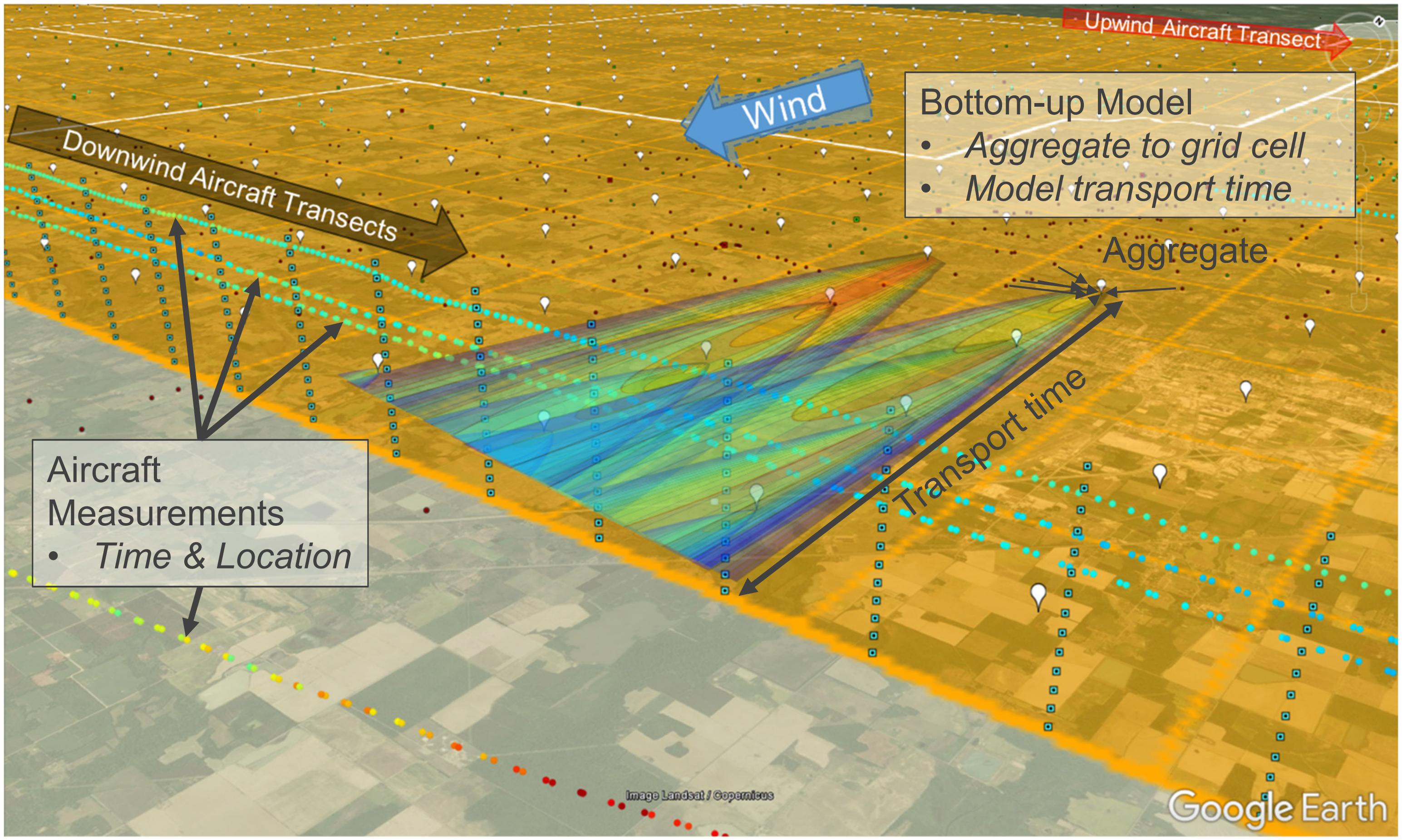
Compare to top-down estimates

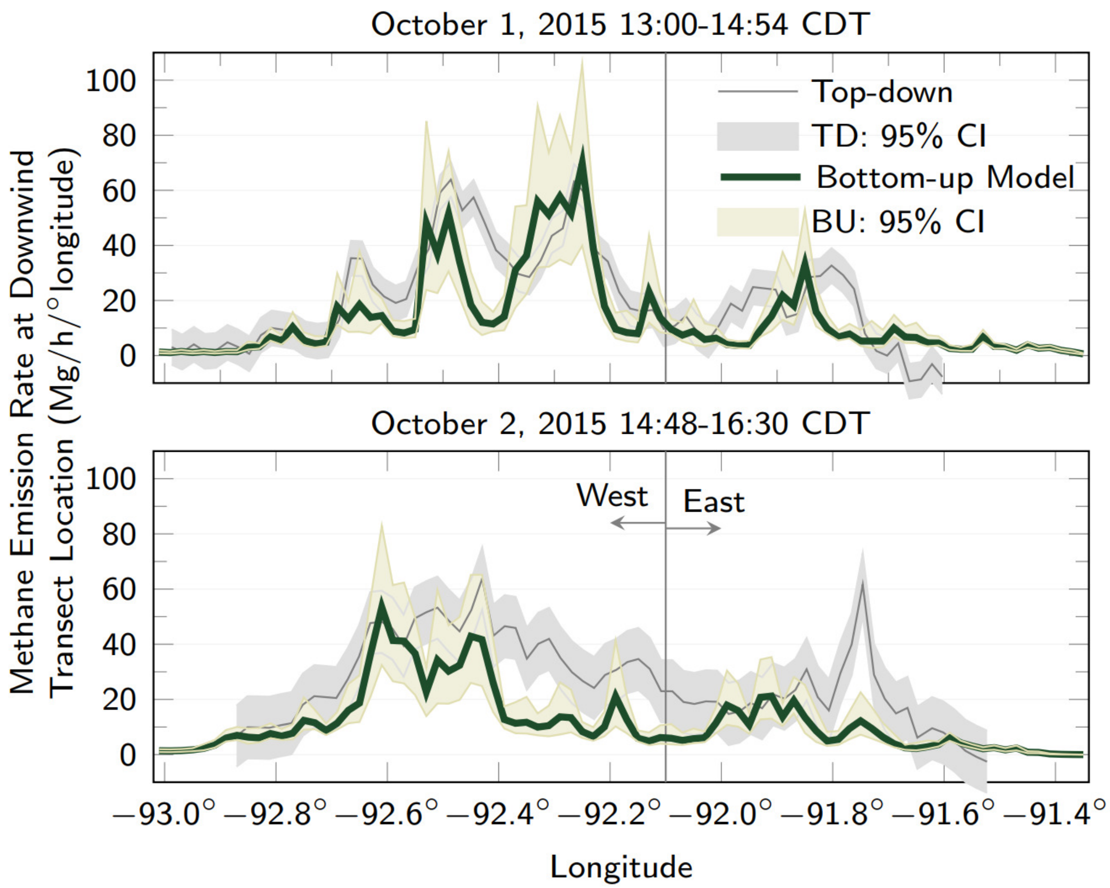


- Error bars shown represent a 95% a confidence interval about the mean result

Study basin emission profiles



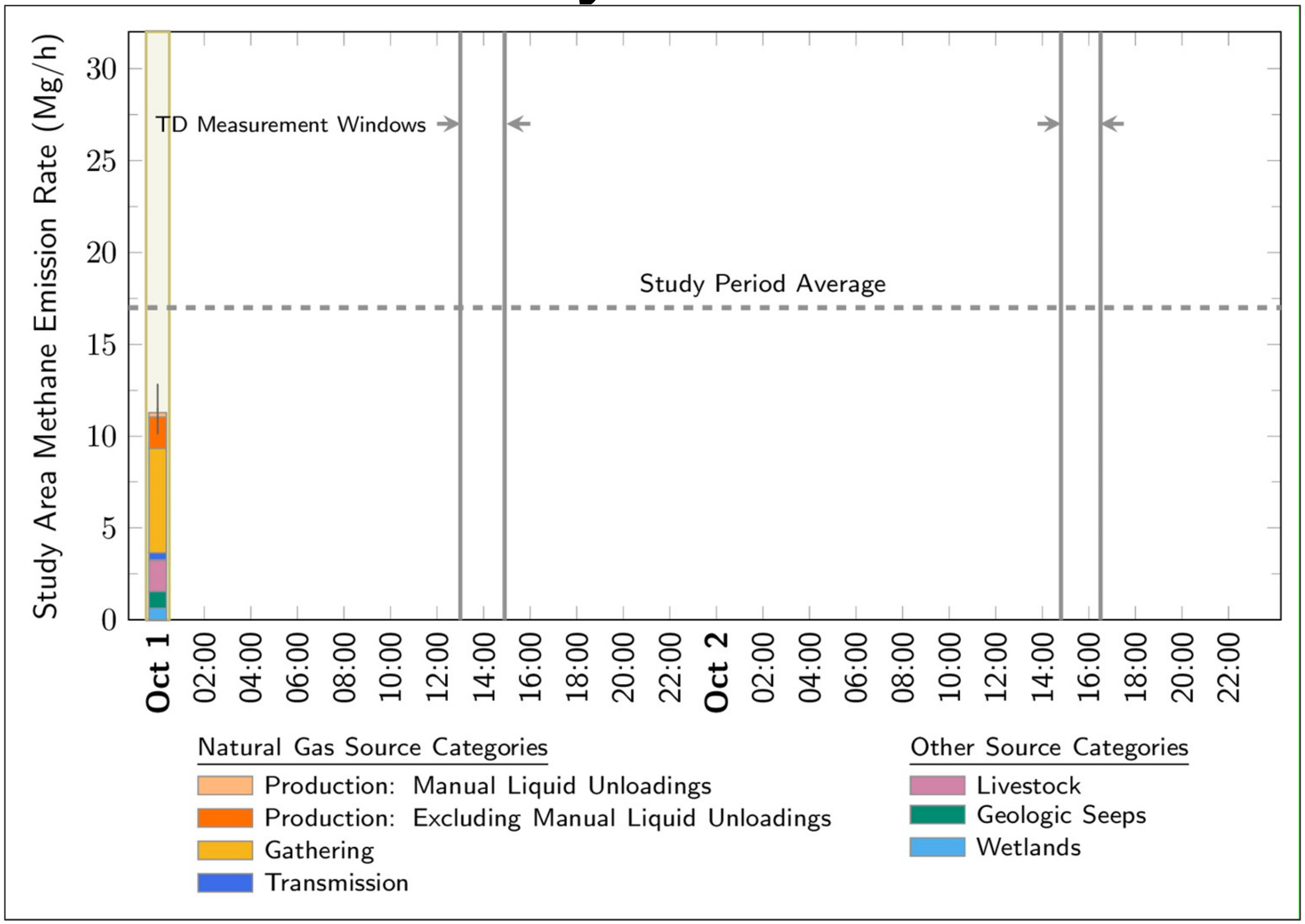
Compare to top-down profiles



<u>Remarkably similar structure</u> in BU and TD emission profiles

→ strong evidence both methods *are estimating the same emissions*

Temporal Variability in Emissions



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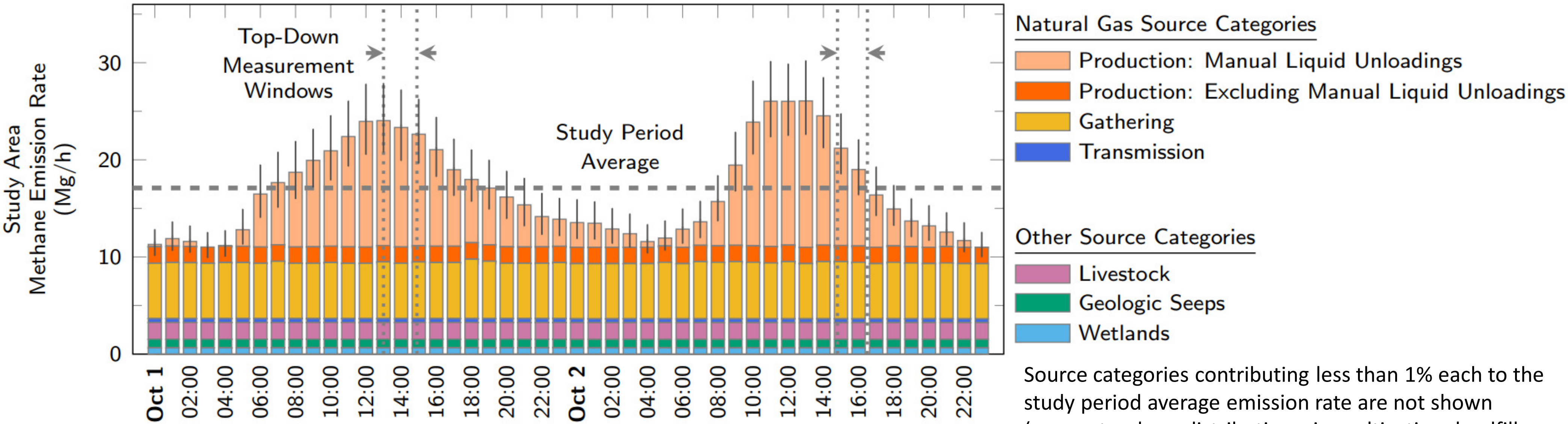
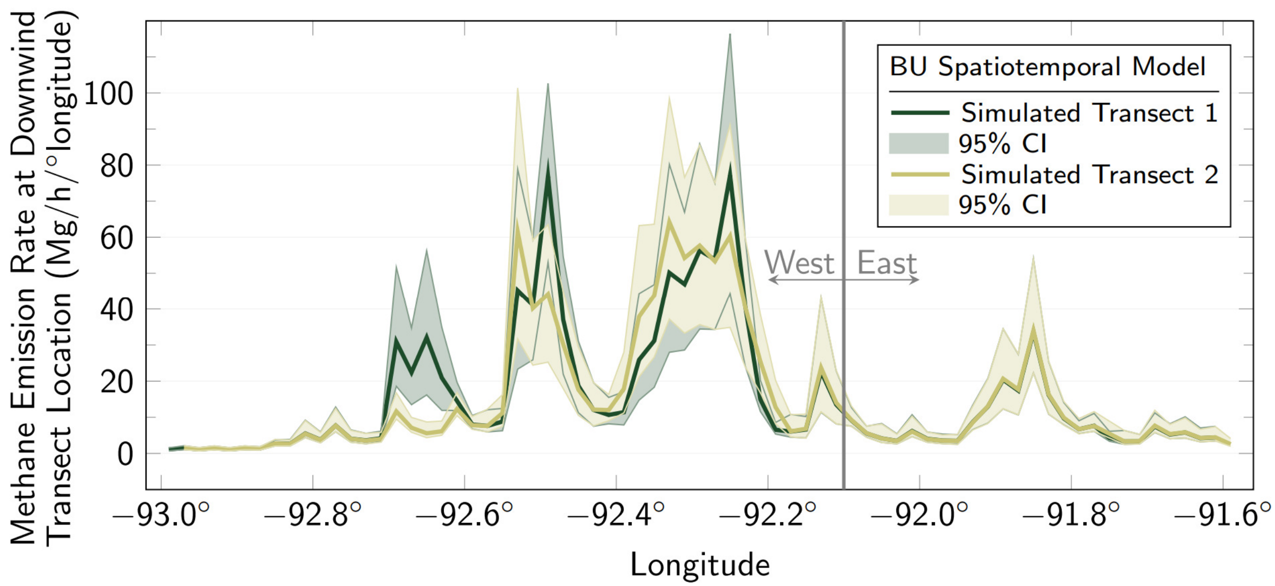
Temporal Variability in Emissions



Source categories contributing less than 1% each to the study period average emission rate are not shown (e.g., natural gas distribution, rice cultivation, landfills, wastewater treatment, etc.)

- Stronger agreement … why?
  - Temporal modeling of BU emissions
  - Spatial modeling of BU emissions
  - Stable winds produced *spatially resolved* TD estimate

What if we had *even better data?*



- Timing at finer scales can impact results when large intermittent sources exist
- Would need activity data at the timescale of aircraft measurements
  - Very difficult , if not impossible

Conclusions

- Inventory and regional mass balance methods are both right … but care is required when comparing them.
  - Same temporal resolution
  - Same spatial resolution
- Fair comparison requires a robust estimate of the temporal variation in emissions
  - To apply to other basins similar data would need to be collected
- Top-down and bottom-up agreement did not require assumptions on the prevalence of ‘super-emitters’
  - TD/BU gap seen in prior studies mostly closed by considering timing of emission events

Guidance for future comparison studies

- Strong guidance for future regional comparisons
  - Recommend simultaneous measurements
  - Multiple techniques are necessary to capture large emitters
- Required activity data → Industry cooperation is critical
  - Need site access for quality measurements
  - Activity data – when and how episodic emissions occur – required for most infrastructure in basin
- Need solid understanding of wind conditions
  - Required wind profiler
- Need simultaneous … or at least recent … measurements of major sources

Peer-reviewed articles resulting from study

Bell C, et al. (2017) Comparison of methane emission estimates from multiple measurement techniques at natural gas production pads. *Elem Sci Anth* 5(0). doi:10.1525/elementa.266.

Conley S, et al. (2017) Application of Gauss's theorem to quantify localized surface emissions from airborne measurements of wind and trace gases. *Atmos Meas Tech* 10(9):3345–3358.

Mielke-Maday I, et al. (2017) (Submitted) Methane source attribution in a portion of a U.S. onshore dry gas basin using ground and airborne measured C_2H_6/CH_4 enhancement ratios.

Robertson AM, et al. (2017) Variation in Methane Emission Rates from Well Pads in Four Oil and Gas Basins with Contrasting Production Volumes and Compositions. *Environ Sci Technol* 51(15):8832–8840.

Schwietzke S, et al. (2017) Improved Mechanistic Understanding of Natural Gas Methane Emissions from Spatially Resolved Aircraft Measurements. *Environ Sci Technol* 51(12):7286–7294.

Vaughn TL, et al. (2017) Comparing facility-level methane emission rate estimates at natural gas gathering and boosting stations. *Elem Sci Anth* 5(0). doi:10.1525/elementa.257.

Vaughn TL, et al. (2018) Temporal Variability Largely Explains Difference in Top-down and Bottom-up Estimates of Methane Emissions from a Natural Gas Production Region. *Proc Natl Acad Sci*.

Yacovitch TI, et al. (2017) Natural gas facility methane emissions: measurements by tracer flux ratio in two US natural gas producing basins. *Elem Sci Anth* 5(0). doi:10.1525/elementa.251.

Zimmerle DJ, et al. (2017) Gathering pipeline methane emissions in Fayetteville shale pipelines and scoping guidelines for future pipeline measurement campaigns. *Elem Sci Anth* 5(0). doi:10.1525/elementa.258.

Acknowledgements

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Thank you

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