Measurement-Based Methane Inventories & Intensities Using Source-Resolved Aerial Data & Robust Analytics

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Current Practices in Detecting Methane Sources

- On-site Leak Detection & Repair (LDAR) surveys using handheld Optical Gas Imaging (OGI) cameras
  - Jurisdictions like British Columbia, Canada regulate 3x/year LDAR surveys at most facilities

- But OGI surveys have many limitations:
  - Can't detect methane in exhaust plumes
  - Limited by line-of-sight access (e.g. tank tops)
  - Subject to operator skill
  - Ineffective at low temperatures
  - Non-quantitative (*despite "QOGI"*)
  - Labour intensive / costly

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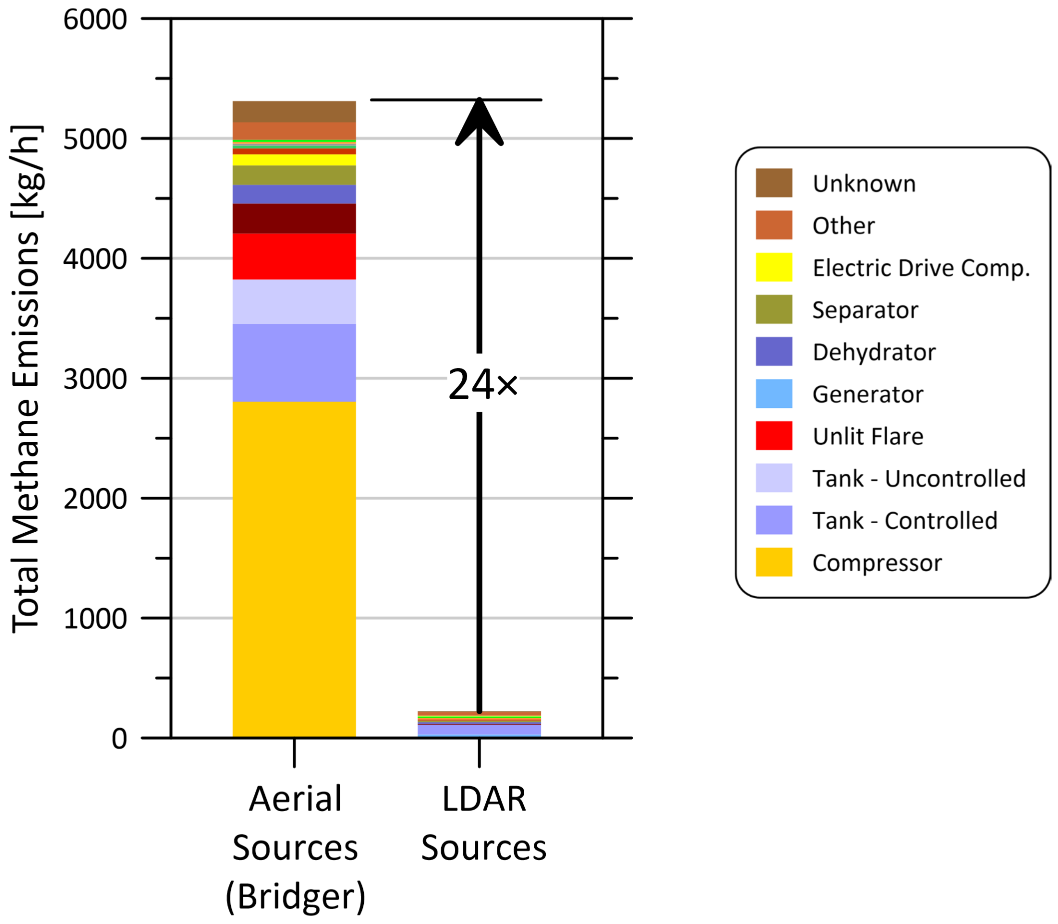
The Limits of OGI Surveys and the Need for "Reconciliation"

- Contrast in reported methane emissions magnitudes via LDAR vs. aerial measurements
  - Set of 362 sites in British Colombia, Canada subject to up to 3×/year regulated OGI LDAR surveys
- Aerial surveys finding ~24× more methane at exact same sites
  - Consistent pattern now seen in multiple studies



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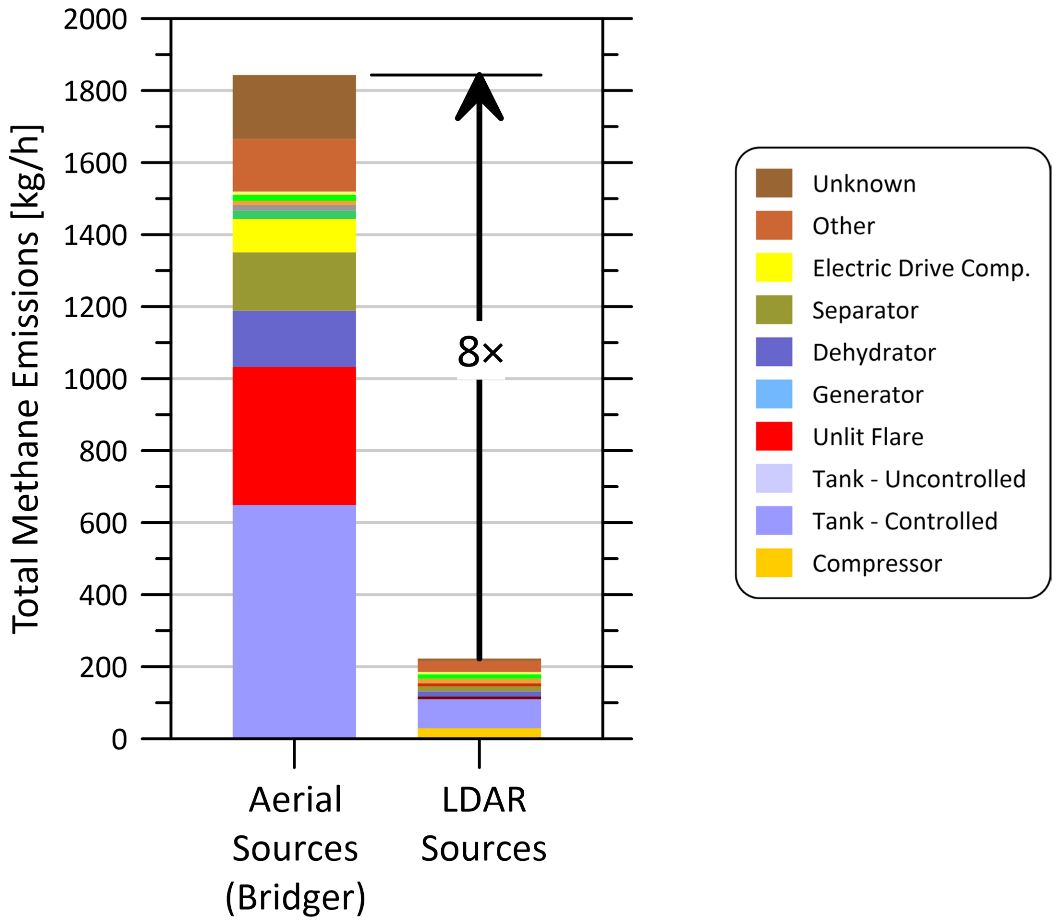
The Limits of OGI Surveys and the Need for "Reconciliation"

- Excluding combustion sources and vented sources in aerial data likely not seen/included in LDAR data
  - Still 8× difference at same sites



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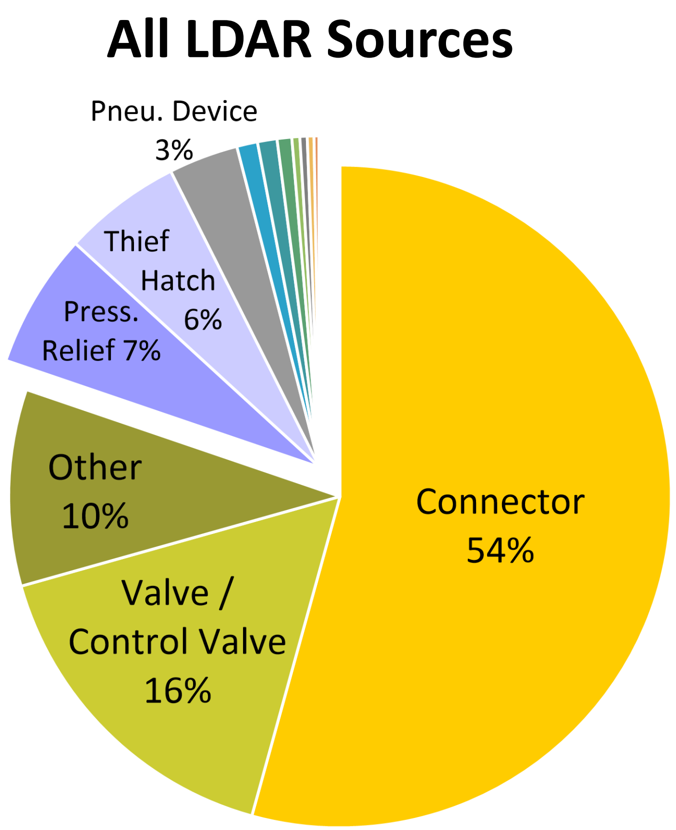
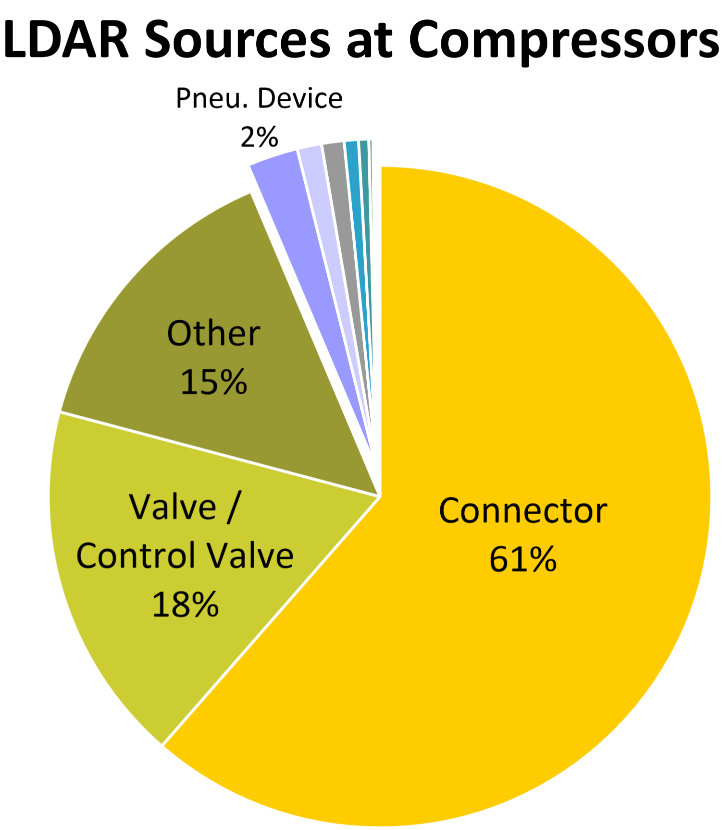
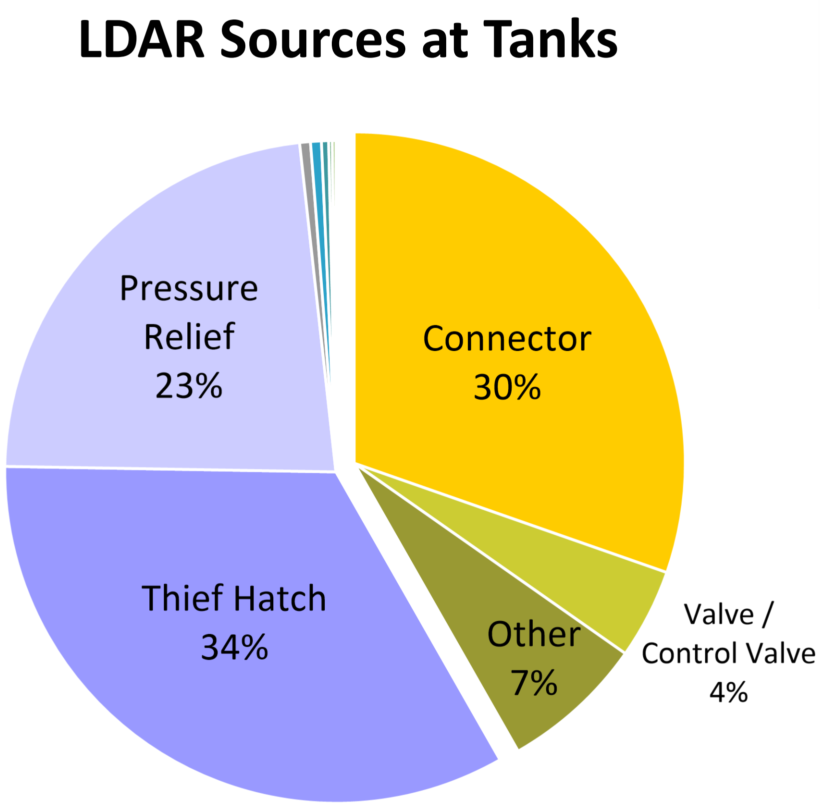
What do Regulated OGI/LDAR Surveys Find?



80% Connectors/Valves/Other



94% Connectors/Valves/Other

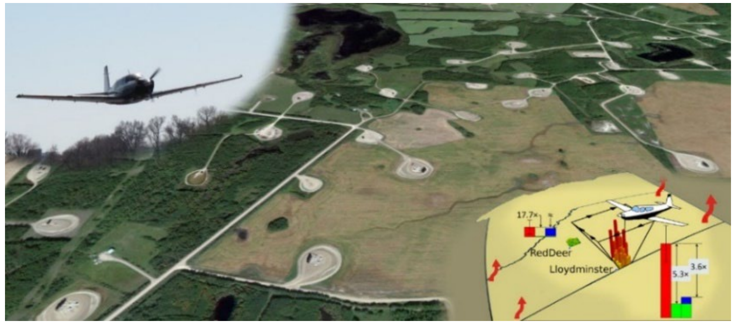


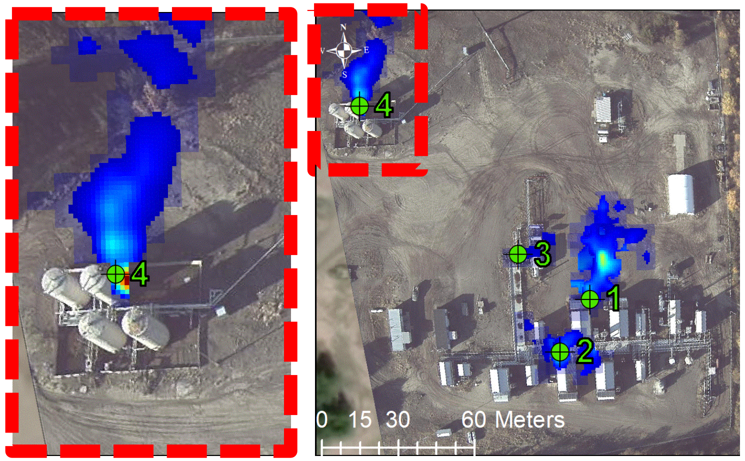
42% Connectors/Valves/Other

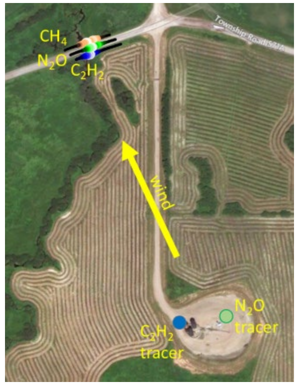
- **Sources detected in OGI surveys are generally *complimentary* to those detected in source-resolved aerial surveys**

Measurement Reporting & Verification (MRV) Goals

- Leverage one or more *measurement* approaches to:
  - Improve accuracy of traditional bottom-up inventory estimates
  - Preserve source-level detail for mitigation / policy / regulation
  - Define *meaningful* uncertainties on estimates
  - Derive robust/verified methane intensities







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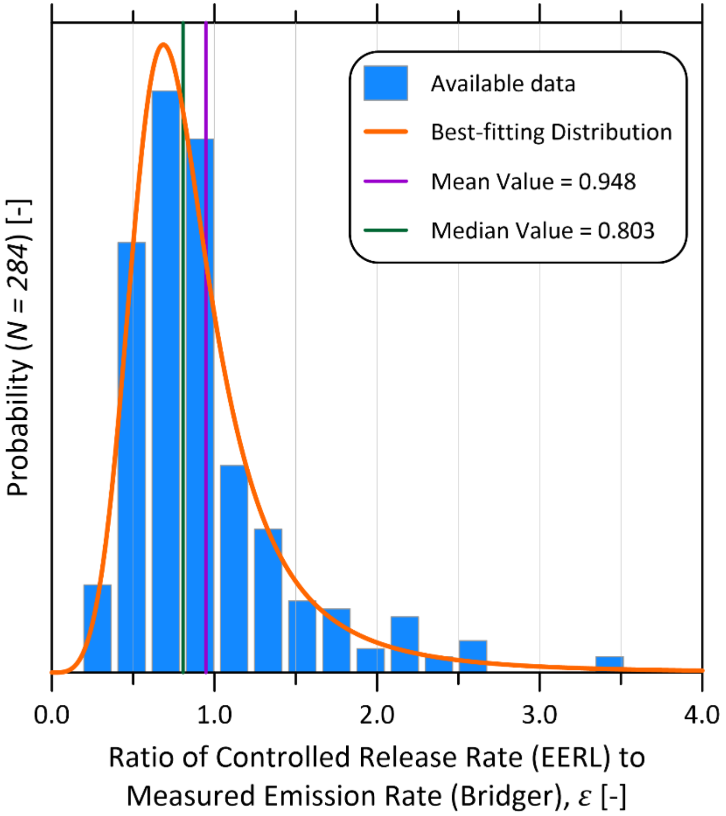
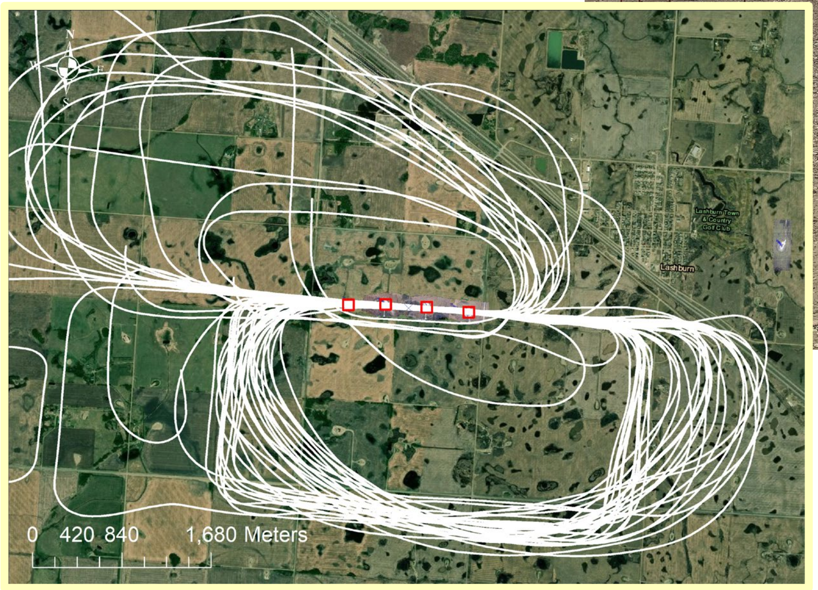
At Least Six Key Challenges for MRV

1. Quantification uncertainty of chosen measurement technology





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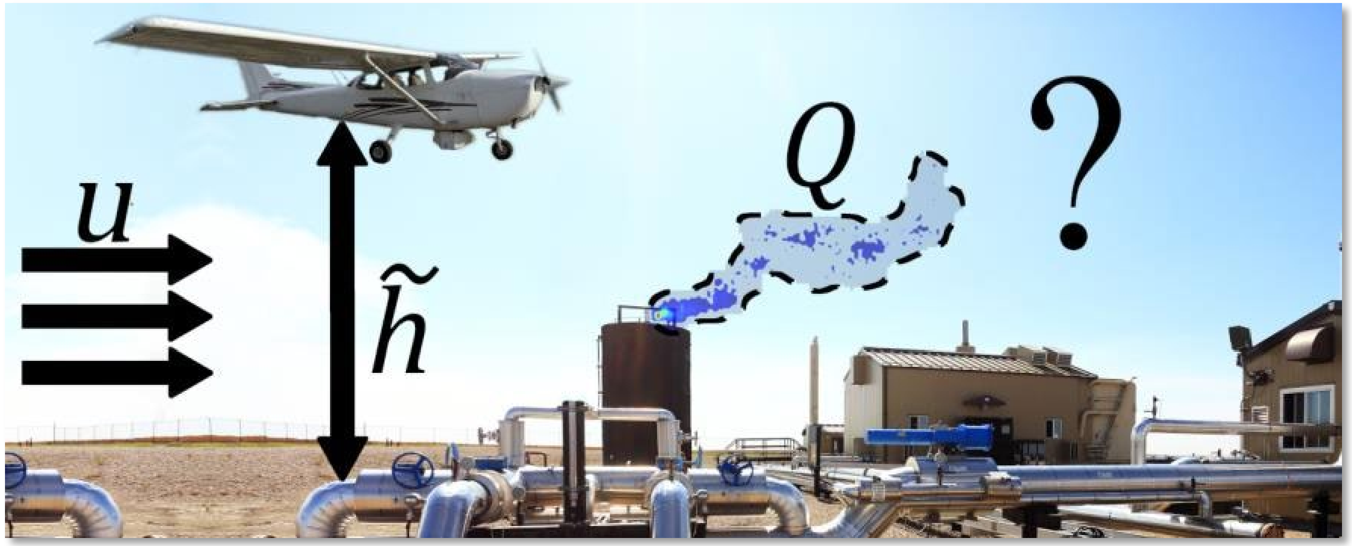
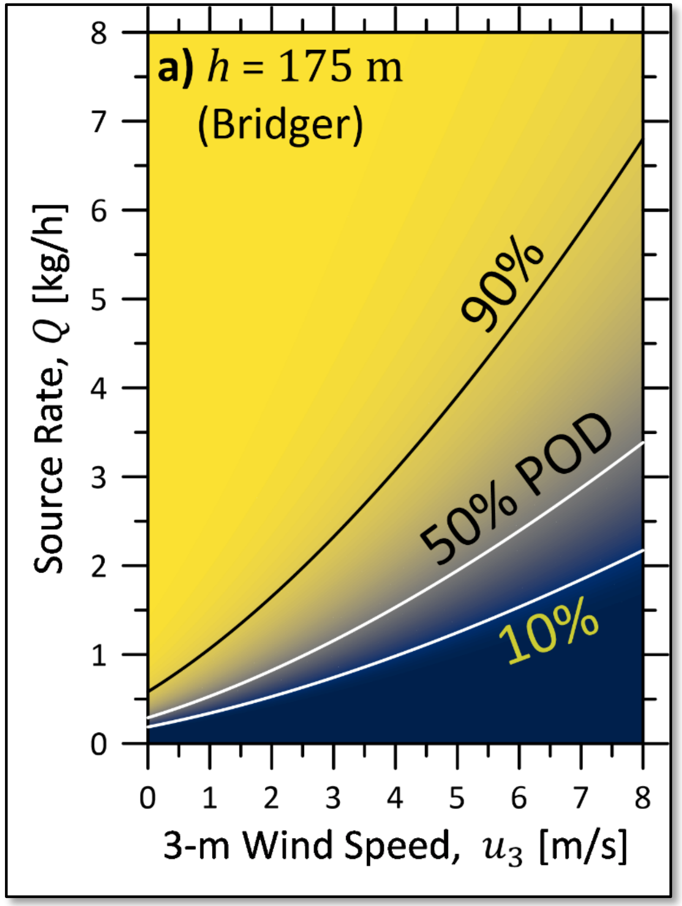
At Least Six Key Challenges for MRV

1. Quantification uncertainty of chosen technology
2. Probability of detection (POD) / sensitivity limit





B.M. Conrad, D.R. Tyner, M.R. Johnson (2023) Robust Probabilities of Detection and Quantification Uncertainty for Aerial Methane Detection: Examples for Three Airborne Technologies, *Remote Sensing of Environment* 288:113499 (doi: 10.1016/j.rse.2023.113499)

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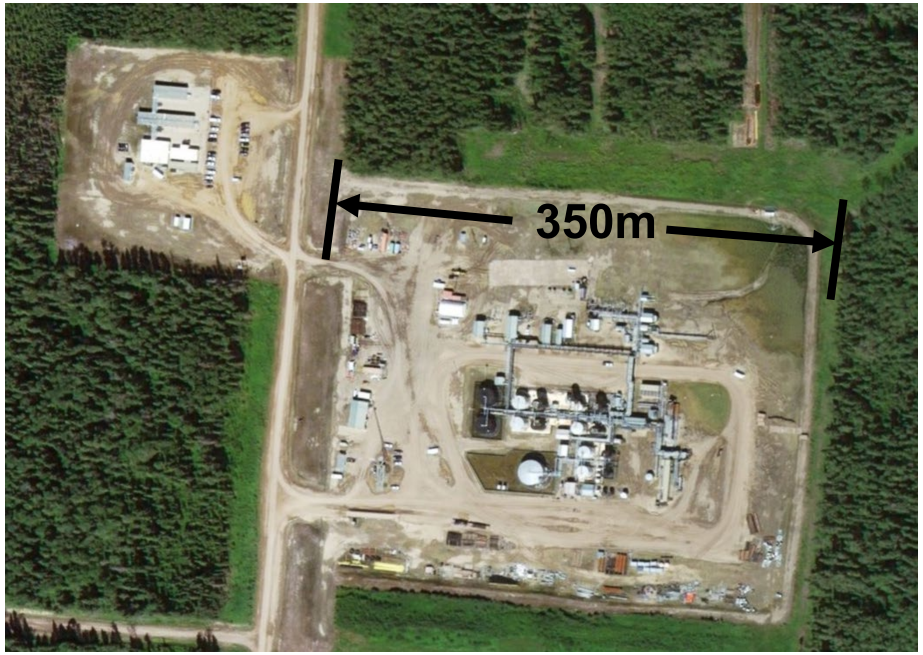
At Least Six Key Challenges for MRV

1. Quantification uncertainty of chosen technology
2. Probability of detection (POD) / sensitivity limit
3. Stark differences among facility types



Contrast between two different “oil facilities”

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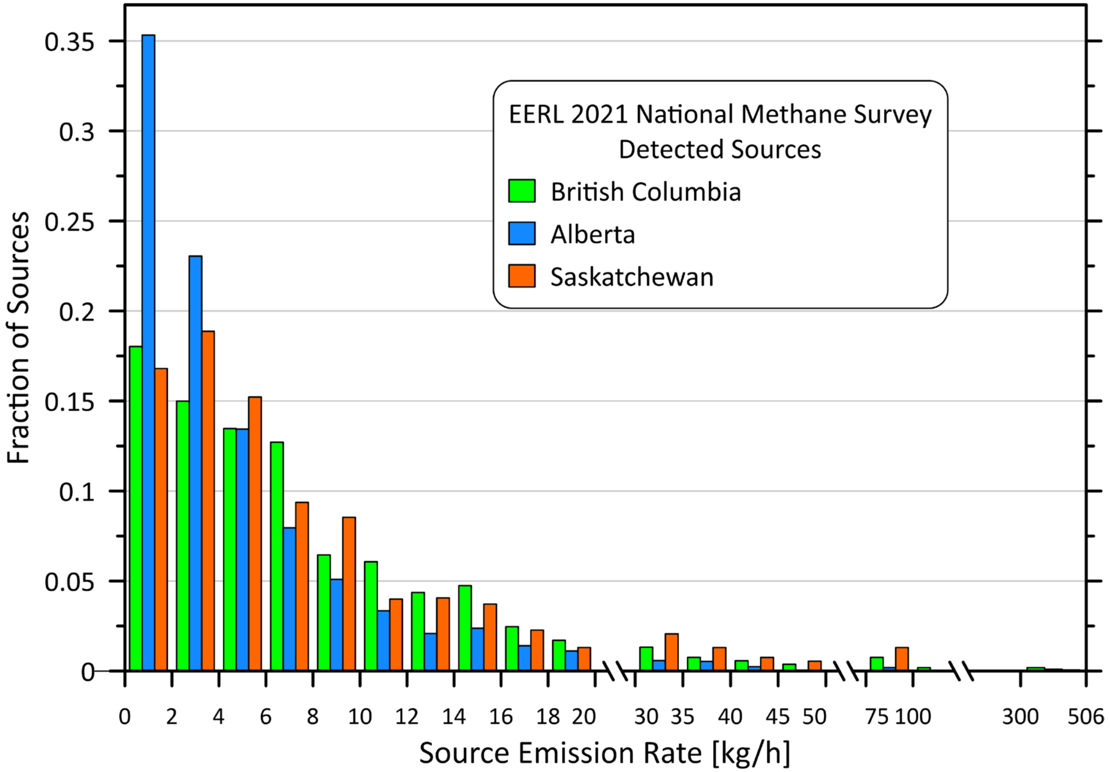
At Least Six Key Challenges for MRV

1. Quantification uncertainty of chosen technology
2. Probability of detection (POD) / sensitivity limit
3. Stark differences among facility types
4. Highly-skewed, **<u>non-smooth</u>**, and potentially discontinuous source distributions



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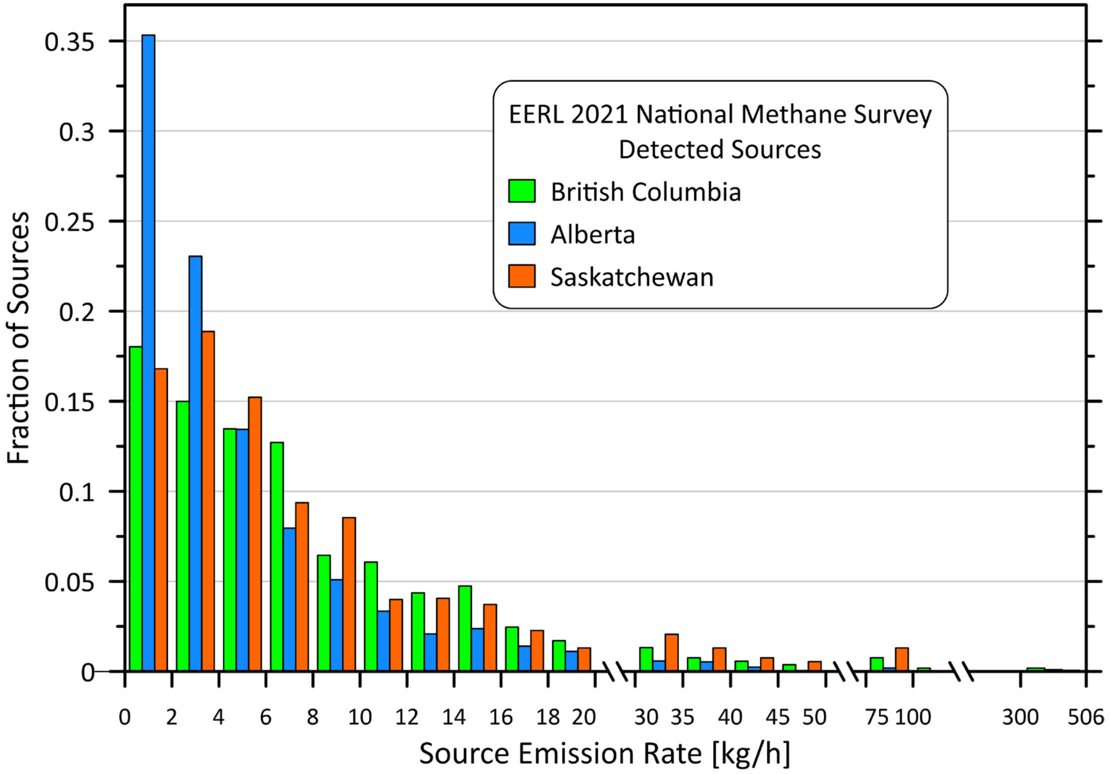
4. Highly-skewed, **non-smooth**, and potentially discontinuous source distributions
5. Finite population effects



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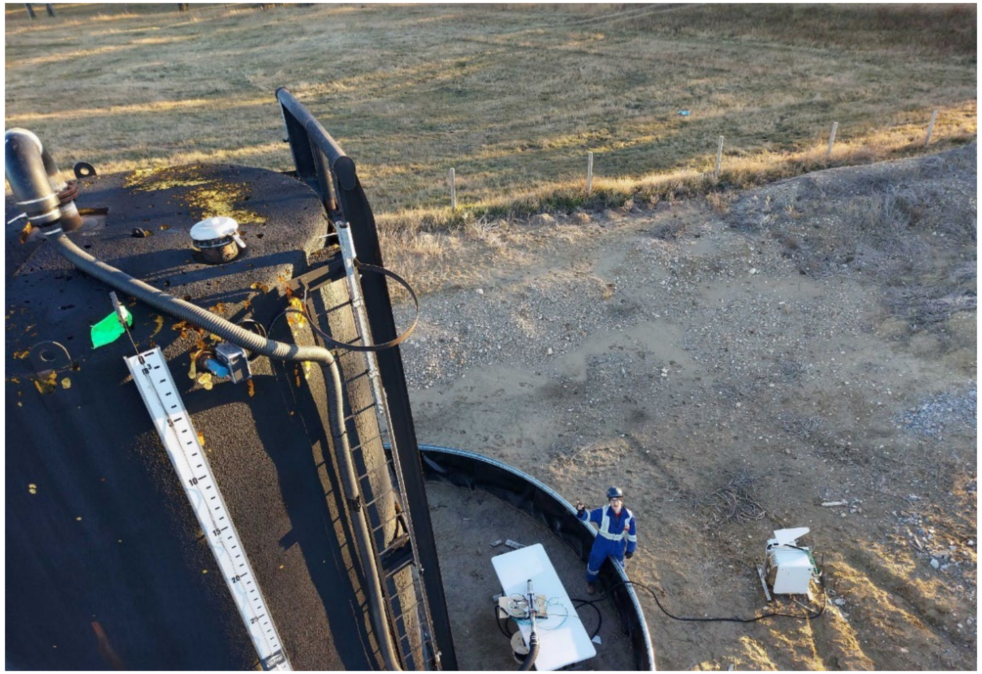
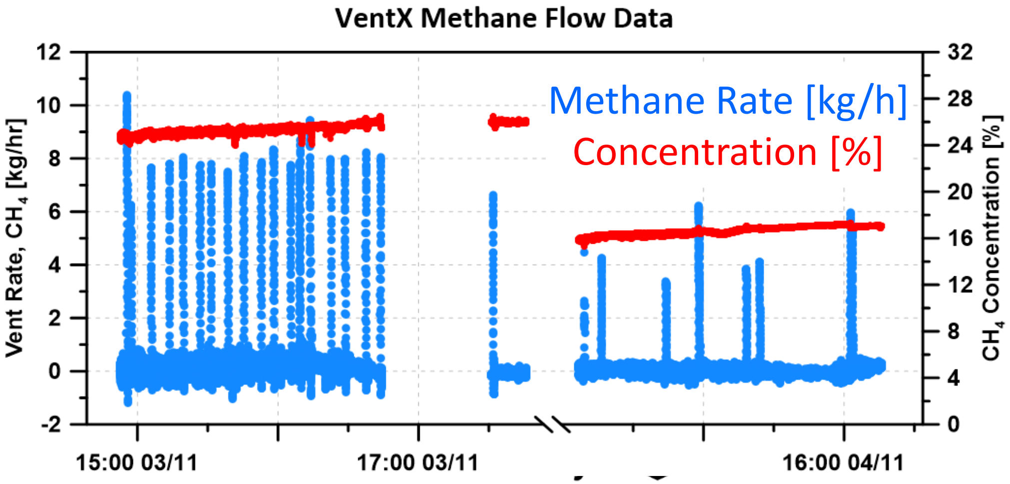
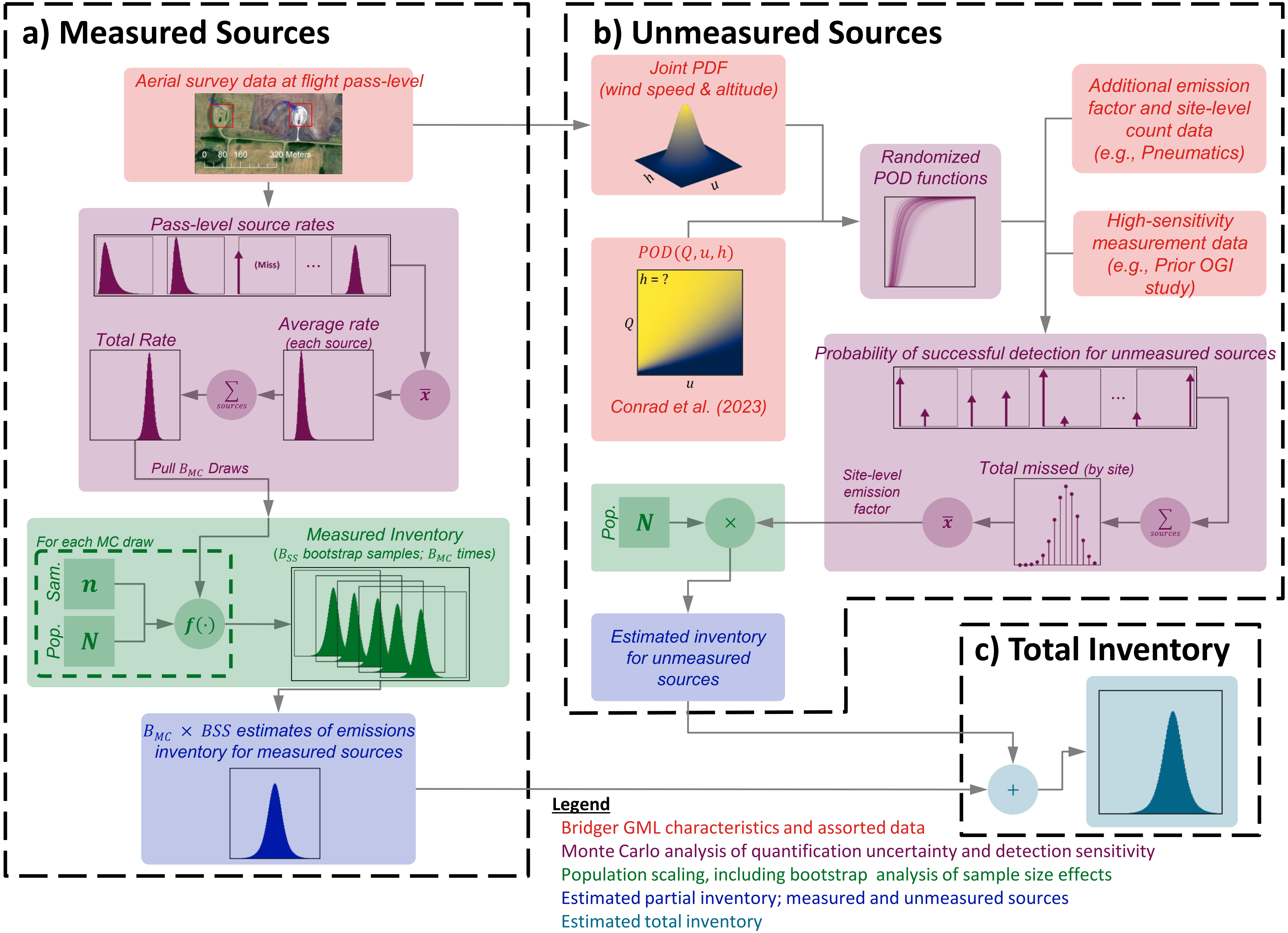
4. Highly-skewed, **<u>non-smooth</u>**, and potentially discontinuous source distributions
5. Finite population effects
6. Intermittency and variability effects at different time-scales
   - *Generally confounded with POD, measurement uncertainty, and sample size effects*





Protocol to Create a Hybrid Top-Down/Bottom-Up ***Measurement-Based*** Inventory



Johnson, Conrad, & Tyner (2023) Communications Earth & Environment (doi: [10.1038/s43247-023-00769-7](https://doi.org/10.1038/s43247-023-00769-7))

EERL 2021 National Methane Census

- National-scale effort
  - ~8200 sites across 3 provinces

Natural Resources Canada / Ressources naturelles Canada

Canada

EDF ENVIRONMENTAL DEFENSE FUND™

BC OGRIS
BC Oil and Gas Research and Innovation Society

BC Oil & Gas COMMISSION

NSERC CRSNG

Environment and Climate Change Canada / Environnement et Changement climatique Canada

BRIDGER PHOTONICS

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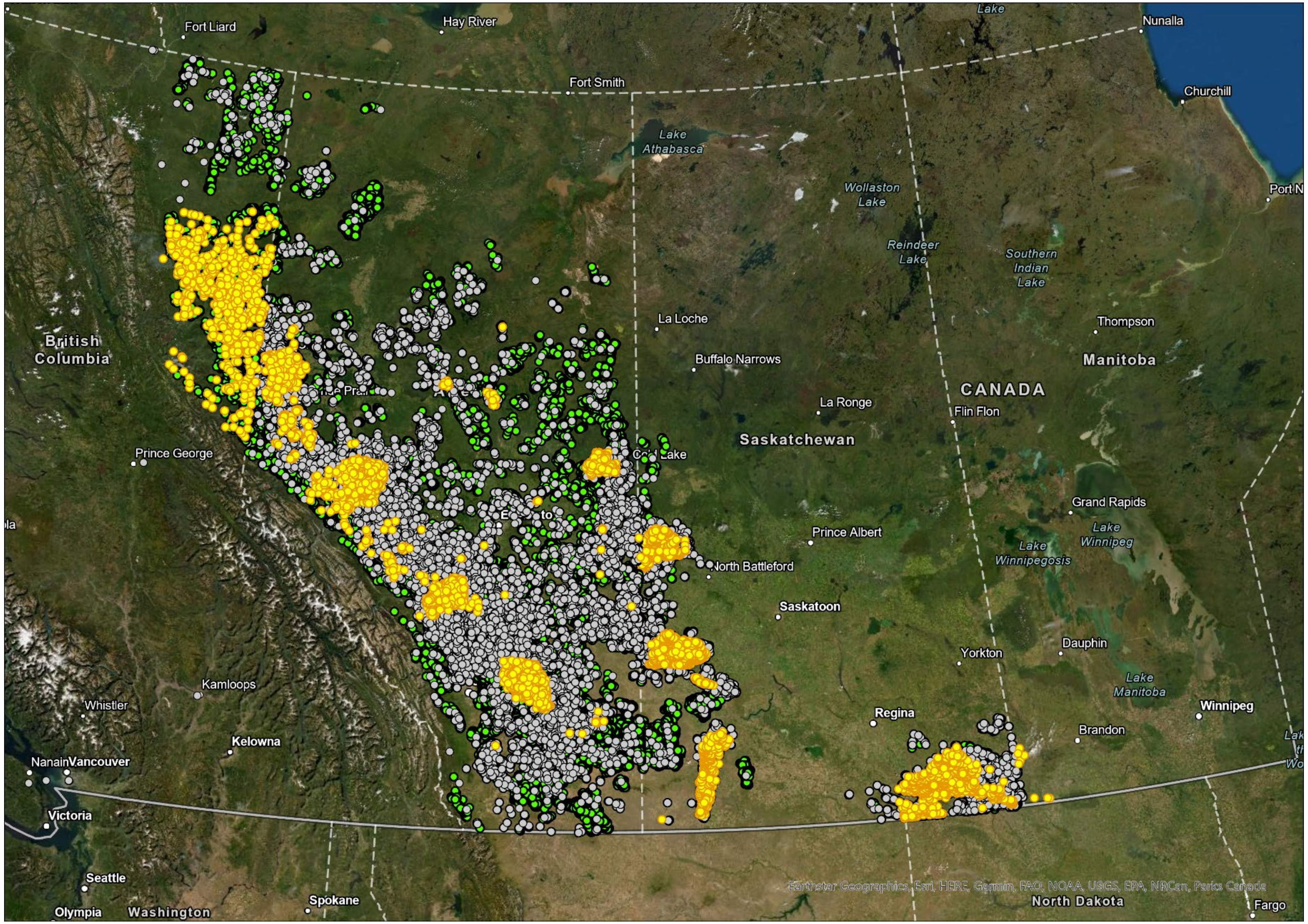
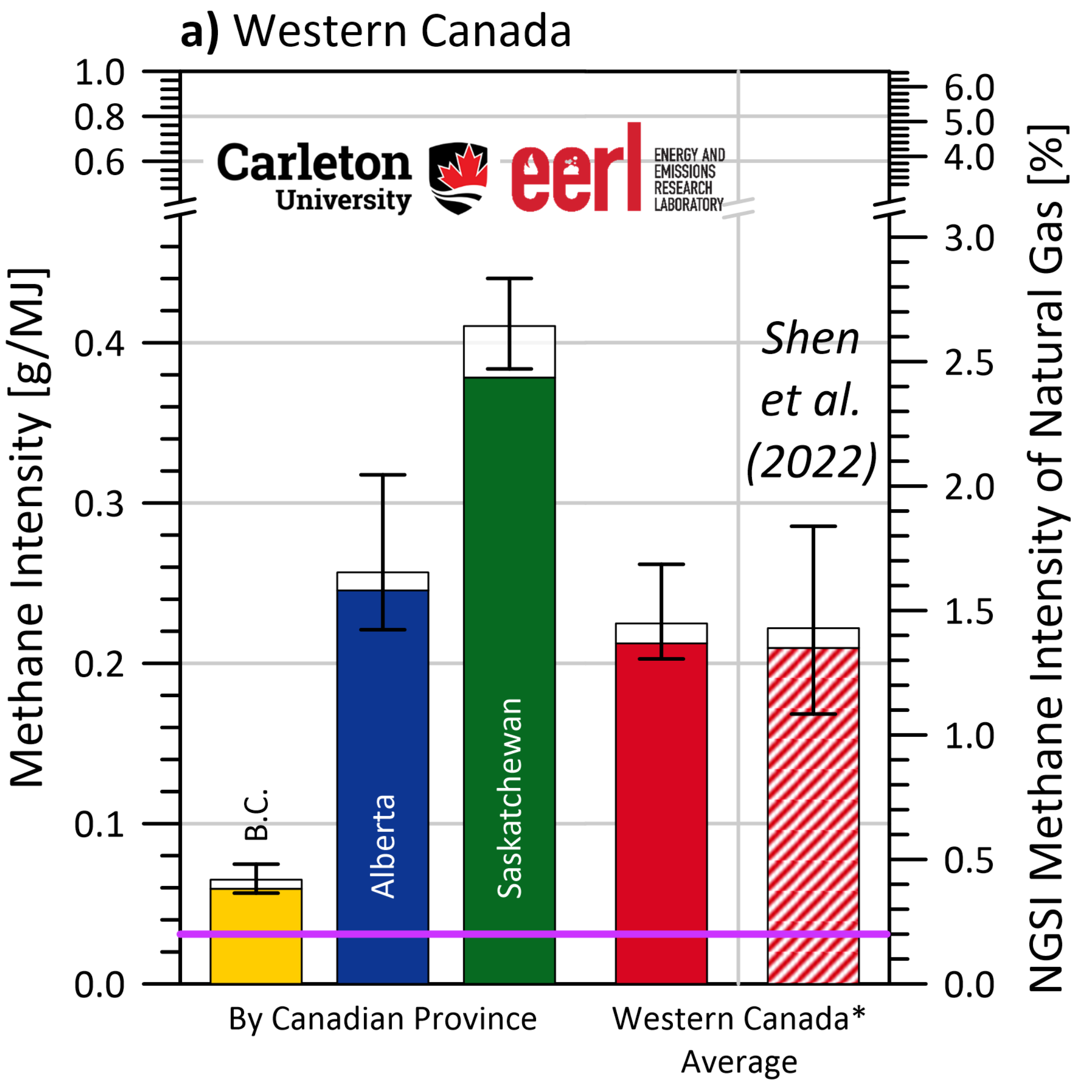


Comparison with Independent Satellite Measurements

- Measured Methane Intensities
  - Methane emitted per unit of energy
  - Underpins global measurement, reporting, & verification (MRV) standards

- **Excellent agreement with completely independent satellite measurements**
  - **“Gap closed” between top-down and bottom-up!**



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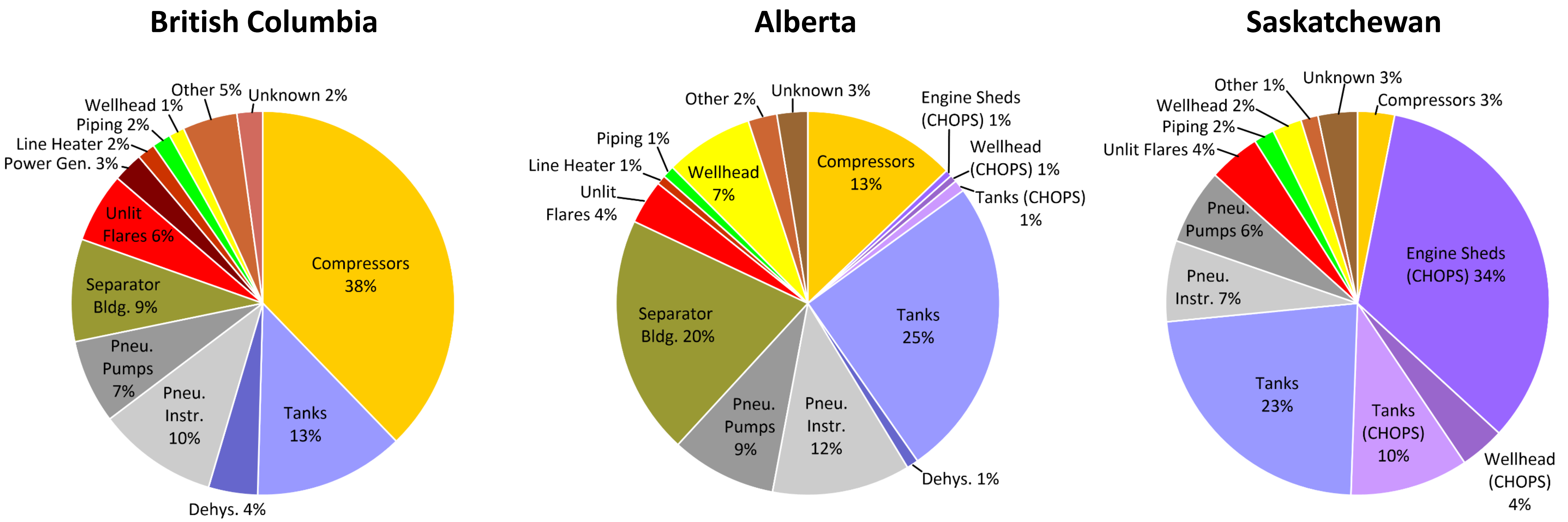
2021 National Measurement-Based Methane Inventory by Source



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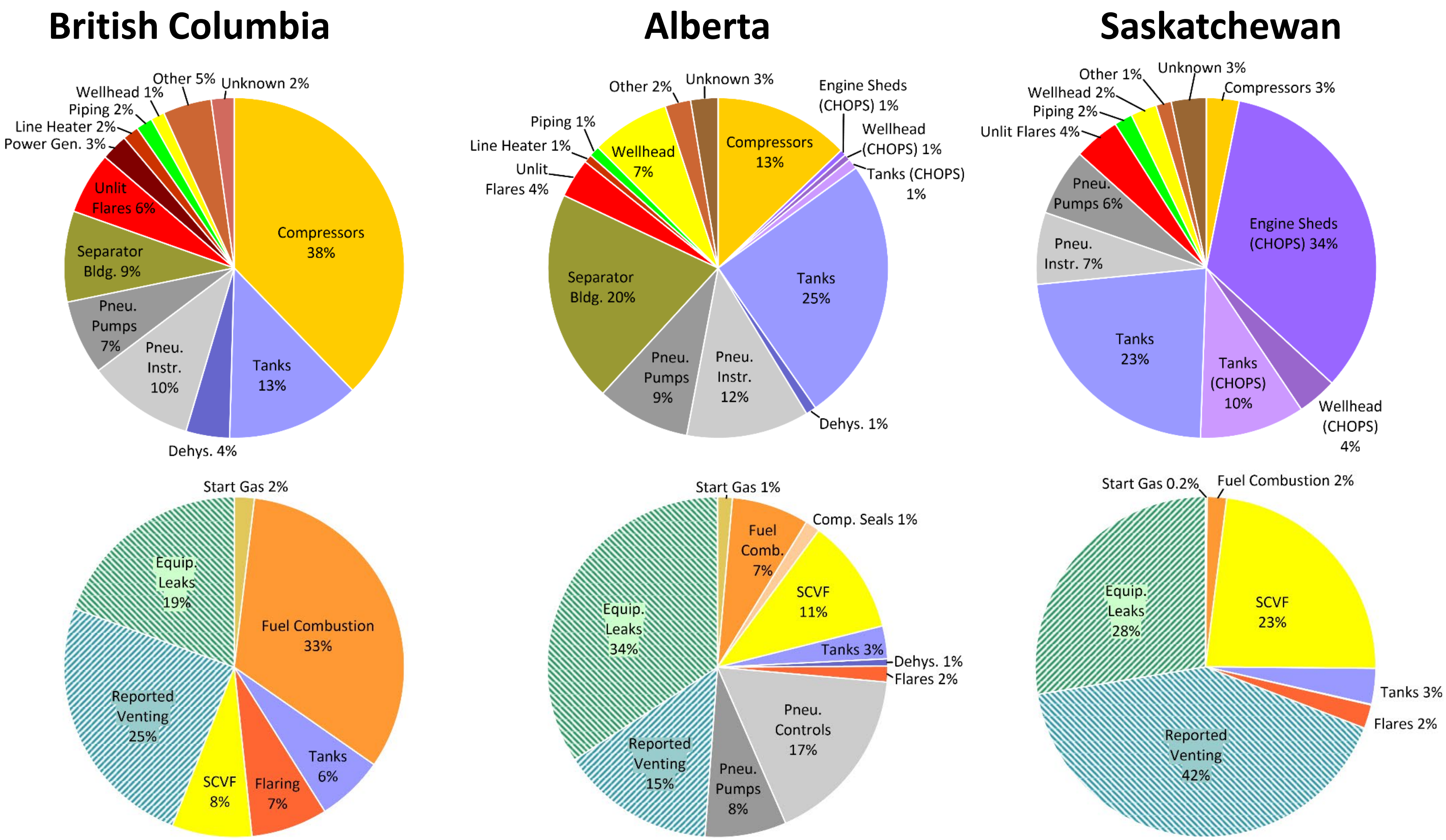
The "Pie Chart Problem"

EERL 2021 Measurement-Based Inventory

Total: 1921 $ktCH_4$

Canada's Official Inventory Estimate

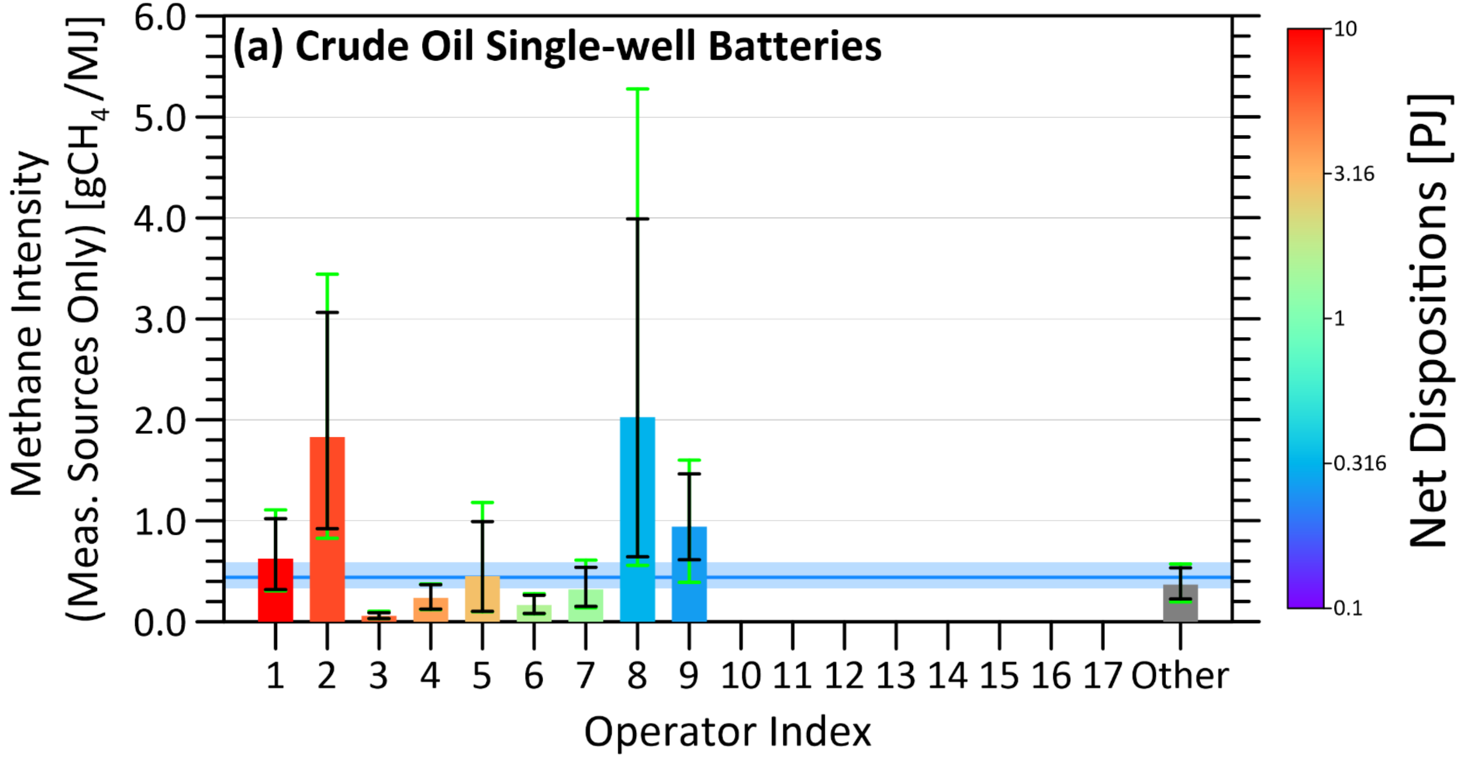
Total: 1227 $ktCH_4$



Operator-Specific Methane Intensities

- Directly comparable methane intensities at the same facility types
  - Operator 2 & 3 have similar production in PJ, but factor ~30 difference in intensity

- **Highlights:**
  - Need for collective action
  - **Hybrid inventory method can accurately quantify intensities with defined uncertainties**
    - Should exceed "gold standard" of OGMP2.0; working with one company to implement



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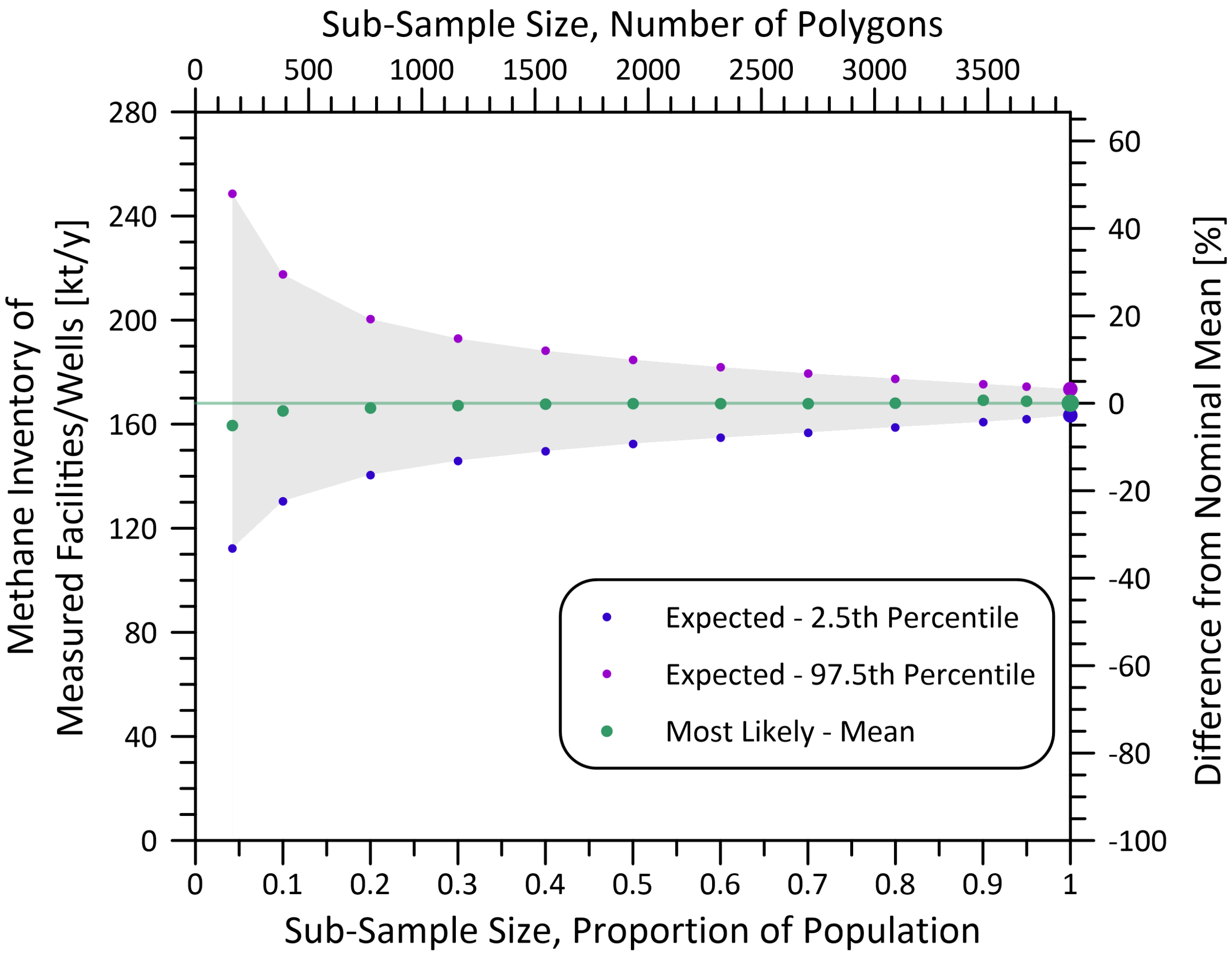
Required Sample Sizes?? – *Ongoing Sub-Sampling Analyses*

- Survey of ~12800 facilities/wells in Saskatchewan in 2023
  - 38 distinct sample strata (i.e., classes of facilities)
- Empirical Convergence Analysis
  - Reproduce inventory with random sub-samples of decreasing size
- **Demonstrates how completely different sub-samples generate equivalent results**



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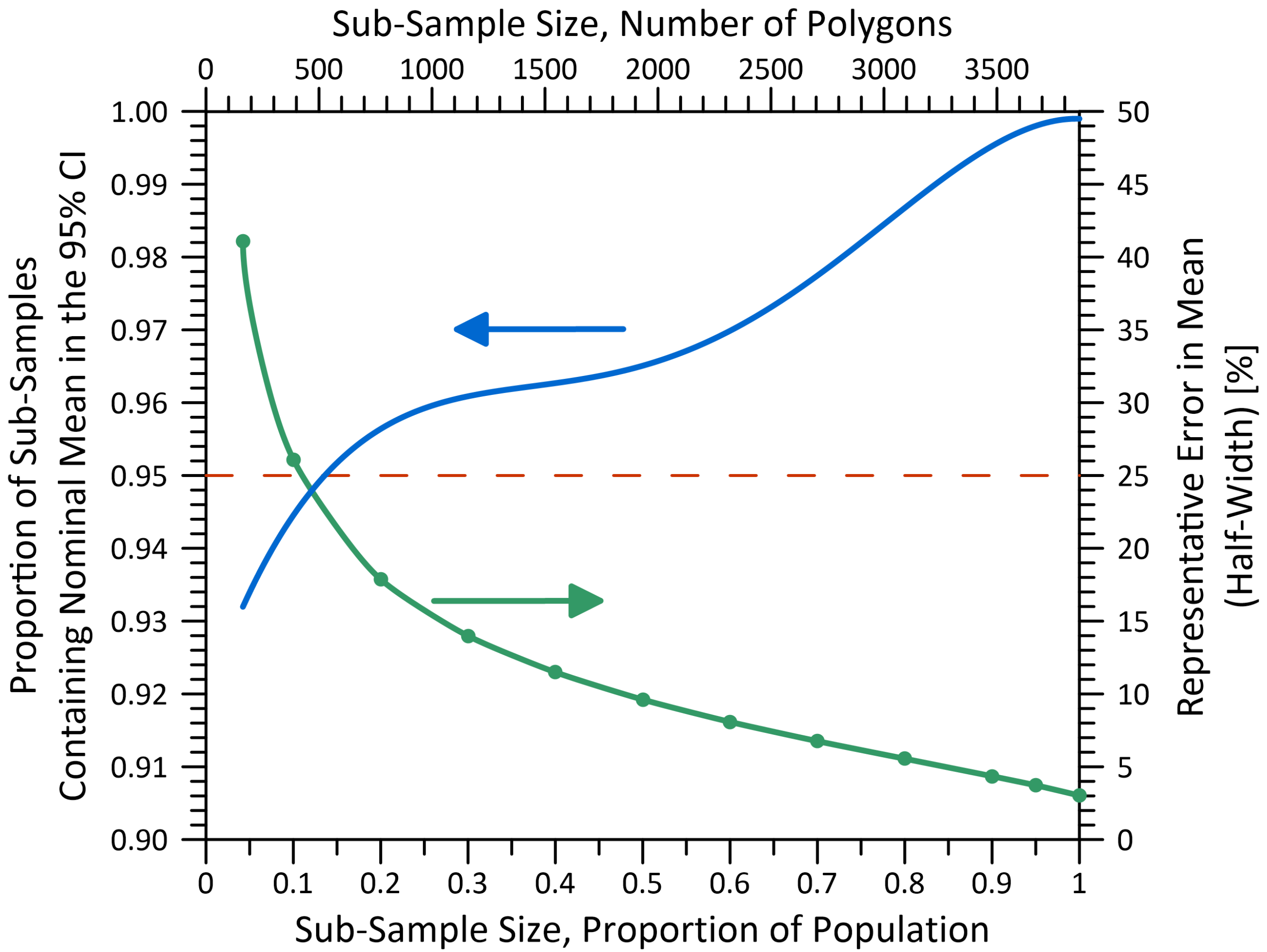
Required Sample Sizes?? – *Ongoing Sub-Sampling Analyses*

- For any **single** random sub-sample, do the derived uncertainties include the actual result >95% of the time?
- Uncertainty grows as sample size reduced (as expected)
- **Currently specific to underlying data, but implies ability to choose sample size to meet target uncertainty**



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Some Closing Thoughts for Discussion

- Optimal MRV combines various measurement approaches with detailed analytics
  - “Reconciliation” should be viewed as an opportunity to combine information

- Published “hybrid” inventory approach can close the gap between top-down and bottom-up approaches while preserving source details
  - Canada is poised to incorporate our direct measurements into their official IPCC inventory report later this year
  - Working with UNEP and EcoPetrol to complete a measurement-based inventory in Colombia

- Ongoing work to evolve and test protocol with potential to define sample-size requirements to achieve a target level of uncertainty

Acknowledgements

Natural Resources Canada / Ressources naturelles Canada

Canada

BC Oil & Gas Commission

BC OGRIS
BC Oil and Gas Research and Innovation Society

NSERC CRSNG

Environment and Climate Change Canada / Environnement et Changement climatique Canada

McCall MacBain Foundation

EDF Environmental Defense Fund™
Finding the ways that work

UN environment programme

Bridger Photonics

PTAC Petroleum Technology Alliance Canada

Montrose Environmental

Greenpath Energy Ltd

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