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COLORADO SCHOOL OF MINES

Title: A Bayesian hierarchical model for localizing and quantifying multi-source methane emissions on oil and gas sites using continuous monitoring systems

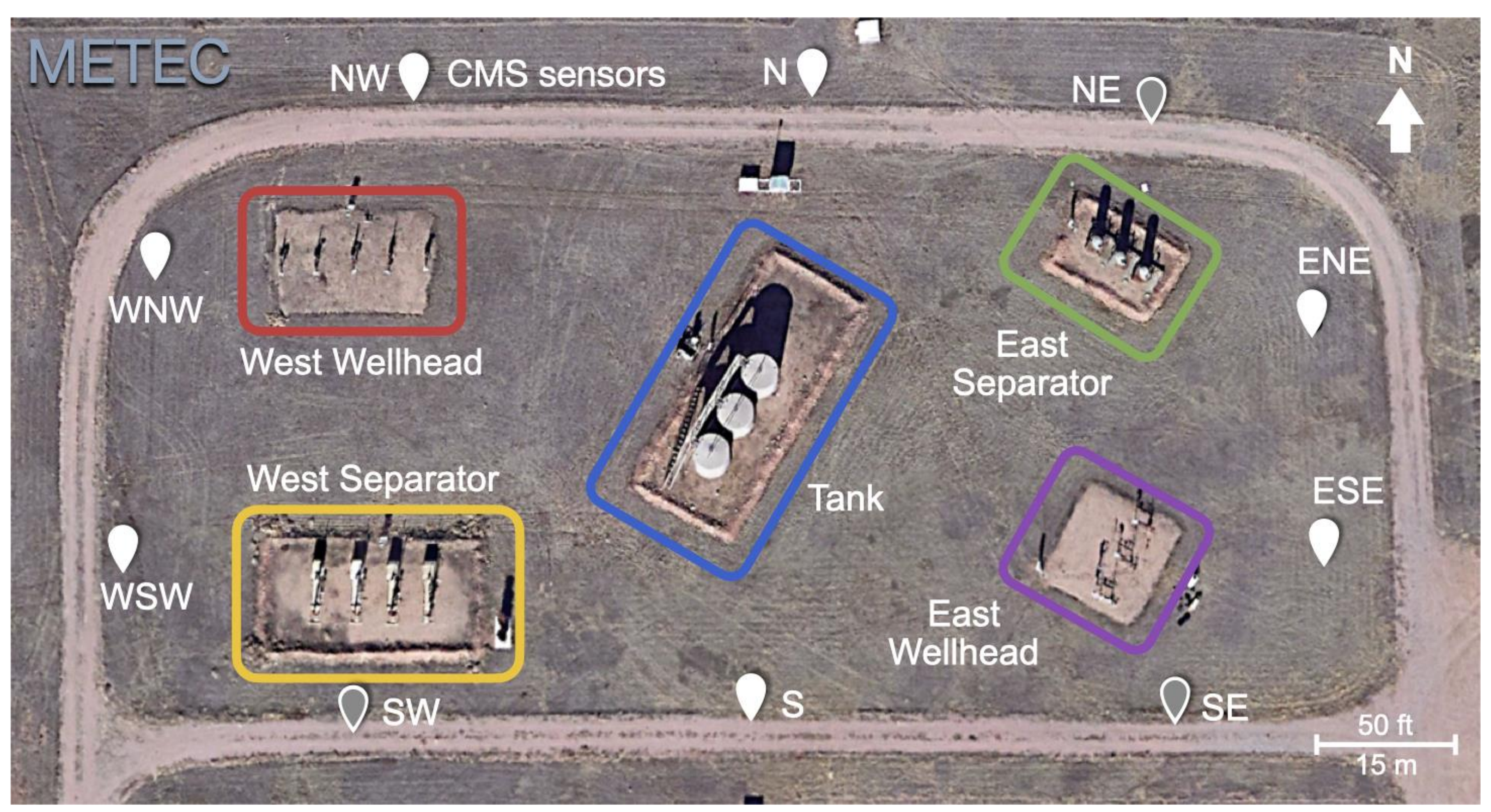
William Daniels
PhD Candidate
Applied Mathematics and Statistics
Colorado School of Mines
wdaniels@mines.edu

Dr. Dorit Hammerling
Associate Professor
Applied Mathematics and Statistics
Colorado School of Mines

ABSTRACT

Continuous monitoring systems (CMS) measure methane concentrations in near real time on a given oil and gas site. This makes them particularly well suited for characterizing intermittent (i.e., sometimes on, sometimes off) emissions at the site-level. However, an inversion algorithm is required to translate the raw concentration measurements from the CMS into estimates of emission source location and rate. Here we describe a Bayesian hierarchical model for performing this task. We highlight the model's suitability in two different use-cases: 1) alerting, where accurate localization estimates are used to inform leak mitigation activities, and 2) inventory development, where the long-term average of the inferred emission rates is used to calculate the annualized emissions inventory at the individual site-level.

1. Background



- Intermittent emissions are hard to characterize at the site-level using only survey-based technologies.
- Continuous monitoring systems (CMS) measure methane concentration in near real time, and hence can capture intermittency at the site-level.
- However, an inversion algorithm is needed to translate raw CMS concentration measurements into emission source location and rate estimates.

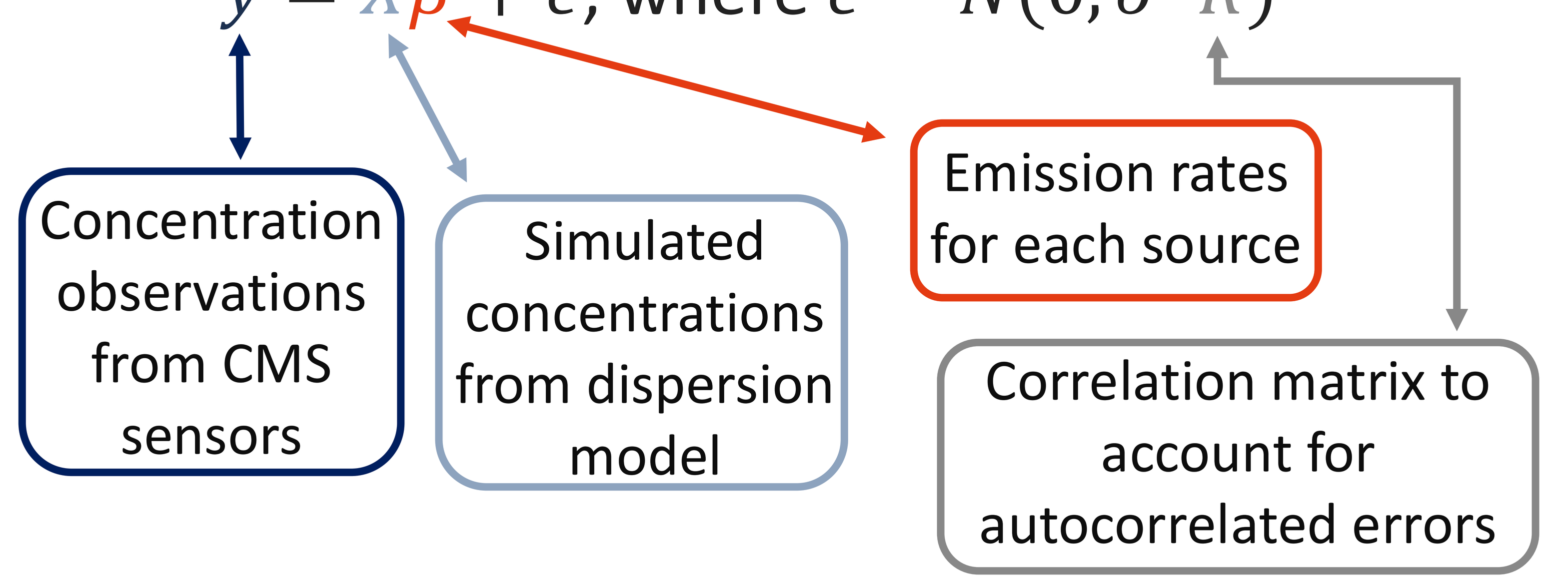
2. Objective

- Previous work established an open-source method for estimating emission source location and rate under the assumption of a single emission source.
- Here we attempt to characterize multisource emissions. We do so by developing a **Bayesian hierarchical inverse model.**

3. Methods

We assume the following model,

$$y = X\beta + \epsilon, \text{ where } \epsilon \sim N(0, \sigma^2 R)$$



and assign the following prior structure,

Rate estimates: $\beta_i \sim \begin{cases} 0 & z_i = 0 \\ \text{Exp}(\tau_i^2 \sigma^2) & z_i = 1 \end{cases}$

Emission indicator: $z_i \sim \text{Bernoulli}(\theta_i)$

Probability of emitting: $\theta_i \sim \text{Beta}(a_i, b_i)$

Error variance: $\sigma^2 \sim \text{Inv-Gamma}(\alpha_1, \alpha_2)$

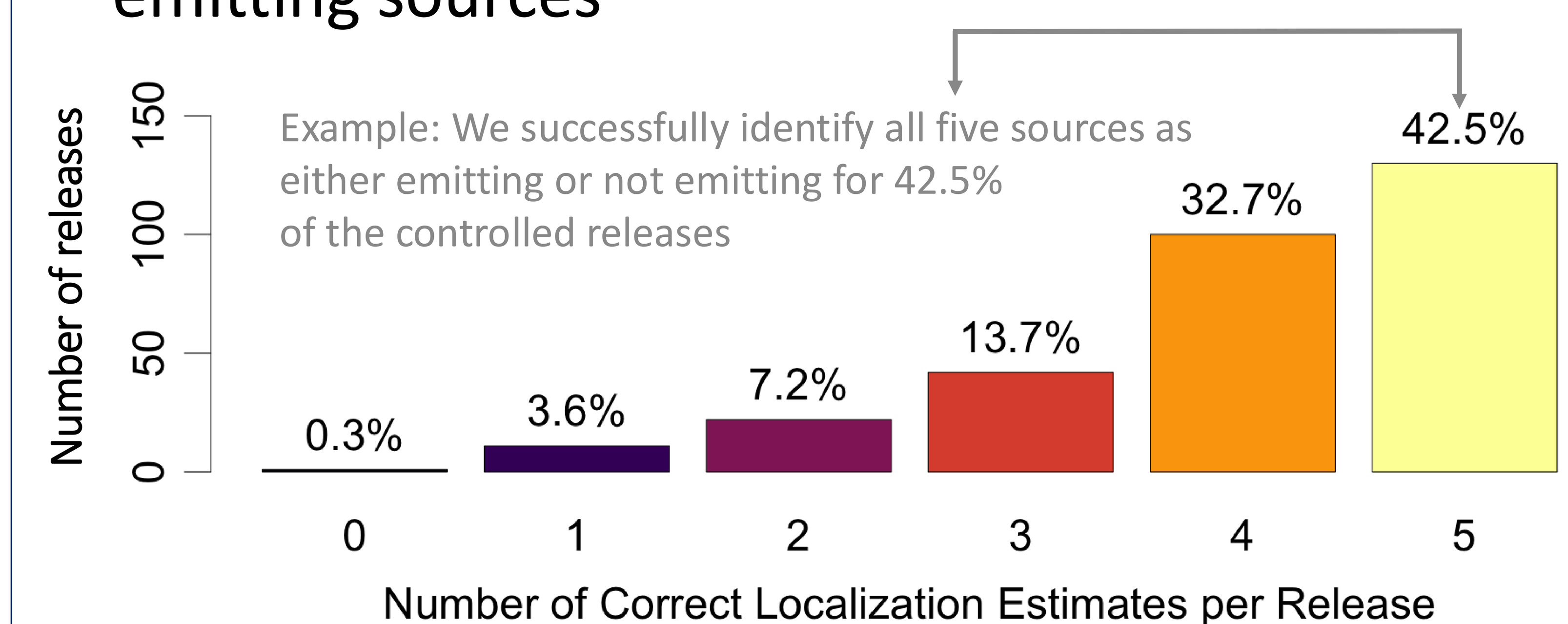
Emission rate scale: $\tau_i^2 \sim \text{Inv-Gamma}(c_i, d_i)$

which has several useful qualities:

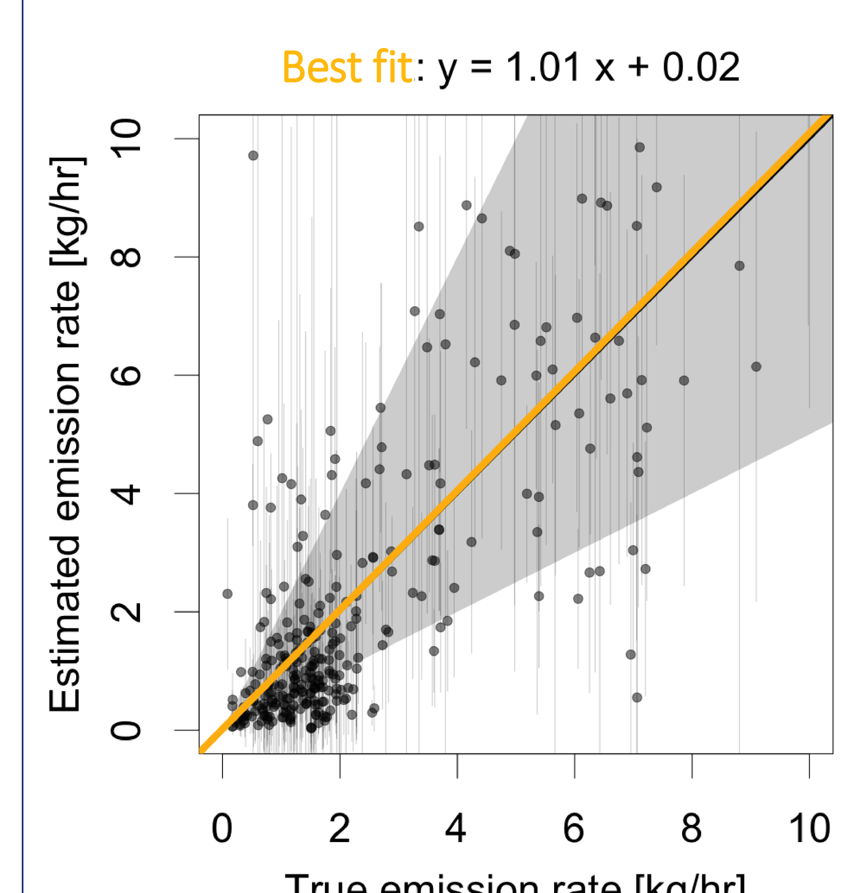
1. "Spike-and-slab" prior on rate estimates allows for 0 kg/hr estimates, which is often the case.
2. Exponential prior on the non-zero rates forces non-negativity, as methane sinks are unlikely on most oil and gas sites.
3. A separate probability of emitting can be specified for each source, as some equipment may leak more frequently than others.

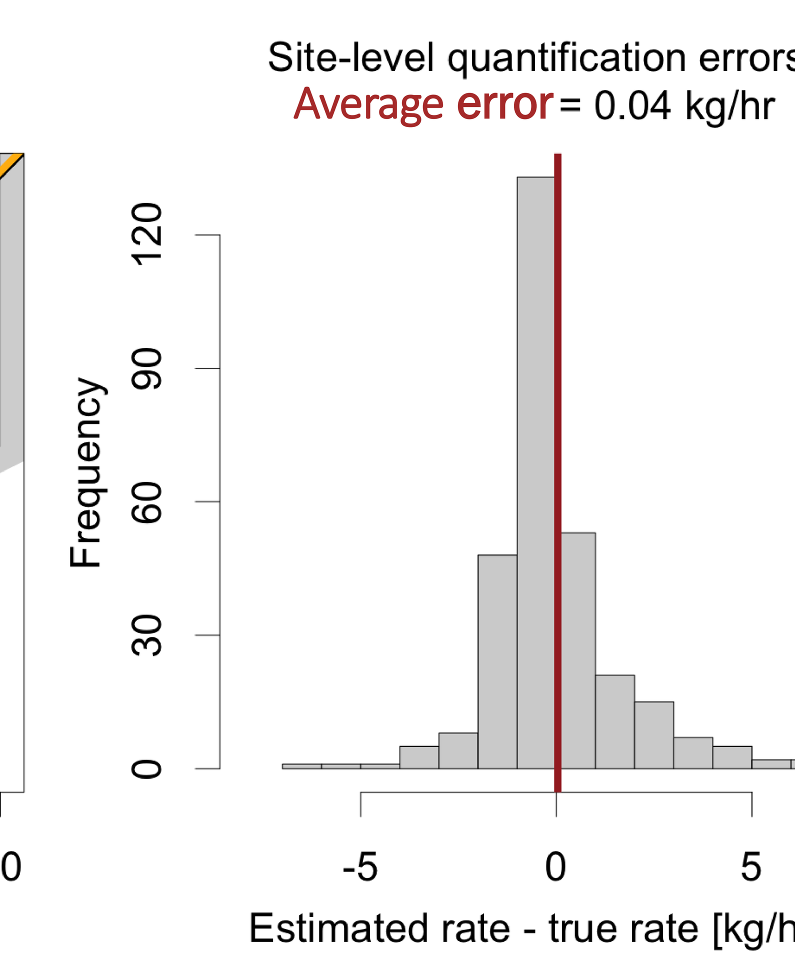
4. Results

- We evaluate the model on 337 multisource controlled releases conducted at METEC. For each release, there are five possible emission sources.
- **Result #1:** Model works in an alerting use-case, as it can successfully identify emitting and non-emitting sources



- **Result #2:** Model works in an inventory use-case, as it produces unbiased emission rate estimates





Colorado State University

The University of Texas at Austin
Cockrell School of Engineering