Applying Bayesian Analysis for Bluer Skies: Point Source Emission Estimation from a Mobile Sensor

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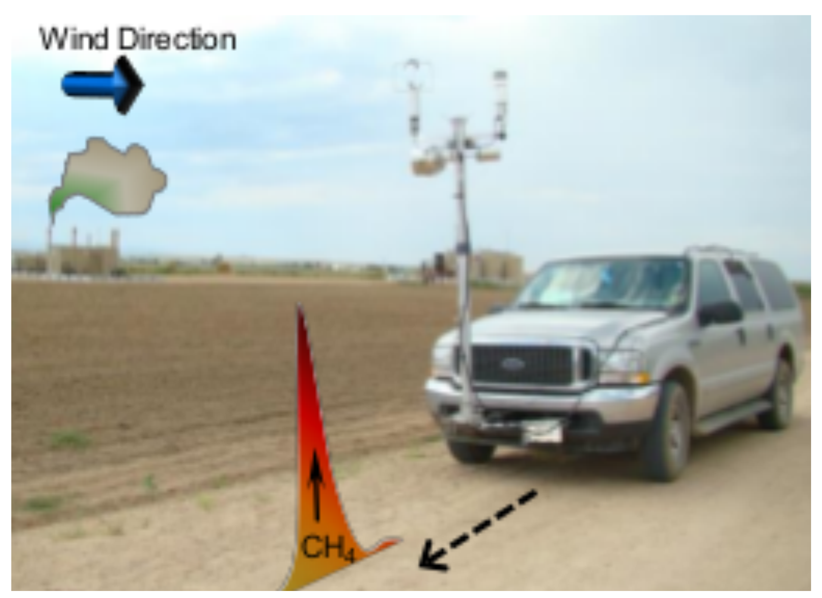
Introduction

Sustainable oil and gas development requires an improved understanding of air emissions from oil and gas production and an enhanced ability to efficiently detect large maintenance related emissions. Methane (CH4) is a green house gas and has been shown to be a significant contributor to global warming [1]. Early mitigation through leak detection and repair can lead to reductions in emissions; however, there is a lack of reliable techniques to infer the location and strength of point source emissions [2]. A new detection and estimation method involving the deployment of a instrumented sensor vehicle and Bayesian source estimation model was proposed by Albertson et al. [2] and this study seeks to understand the impact of the choice of prior on the results.

Measurement Description

- Sampling platform: SUV containing concentration measurement instruments, a computer control system, and battery systems.
- CH4 was measured at a 1 Hz time resolution using a G1301-fc cavity ring-down spectrometer (Picarro, Inc., Santa Clara, CA, USA).
- Primary wind field data were acquired using a model 81000V Ultrasonic Anemometer (R.M. Young, Inc., Traverse City, MI, USA).
- Location was recorded using a Hemisphere Crescent R100 Series GPS system (Hemisphere GPS, Calgary, AB Canada)



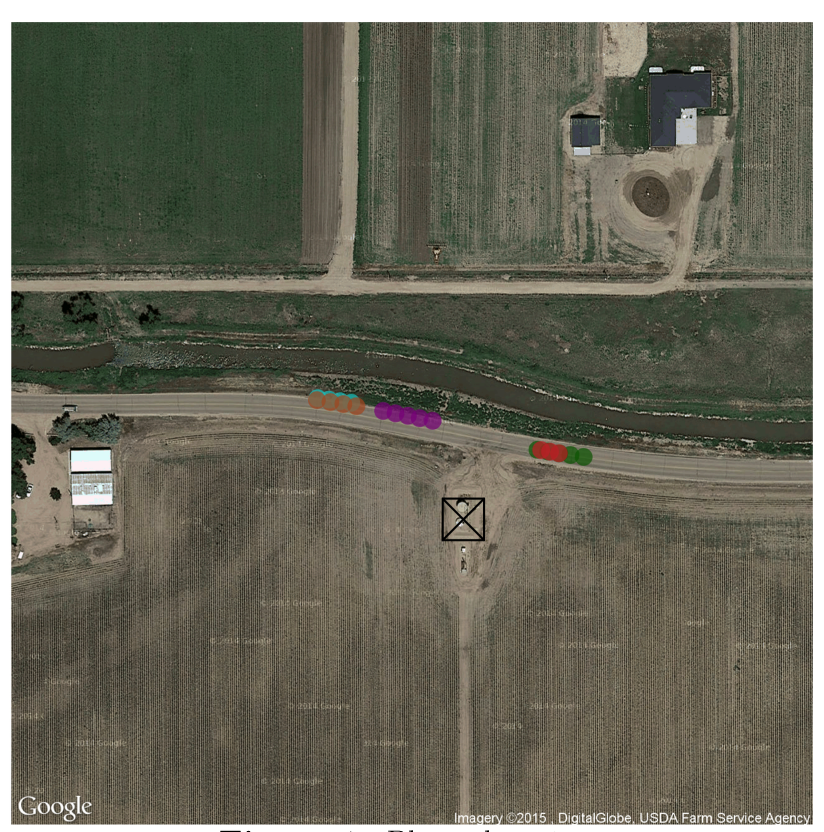


Figure 1: Plume locations

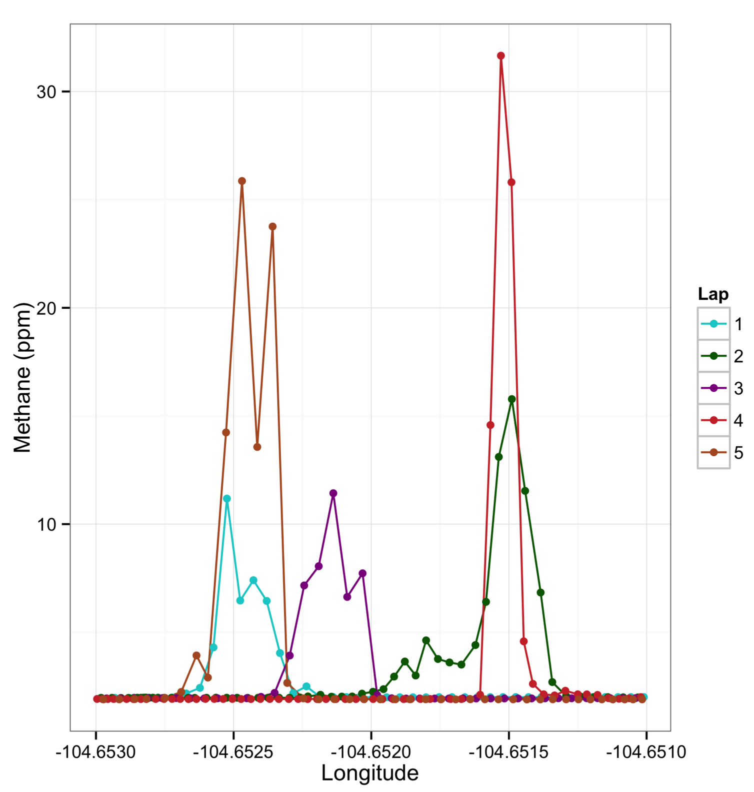


Figure 2: Methane Transects by Plume

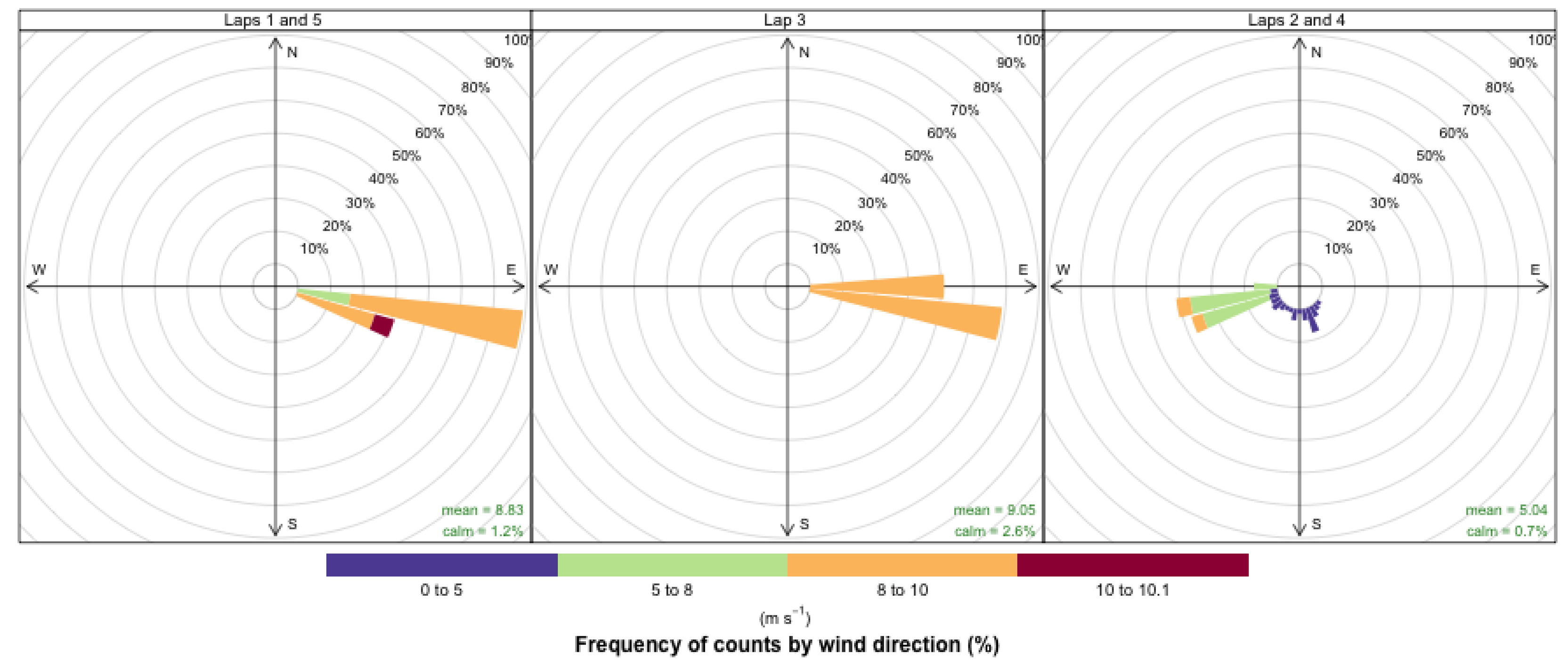


Figure 3: Windrose for corresponding plumes.

Model Development

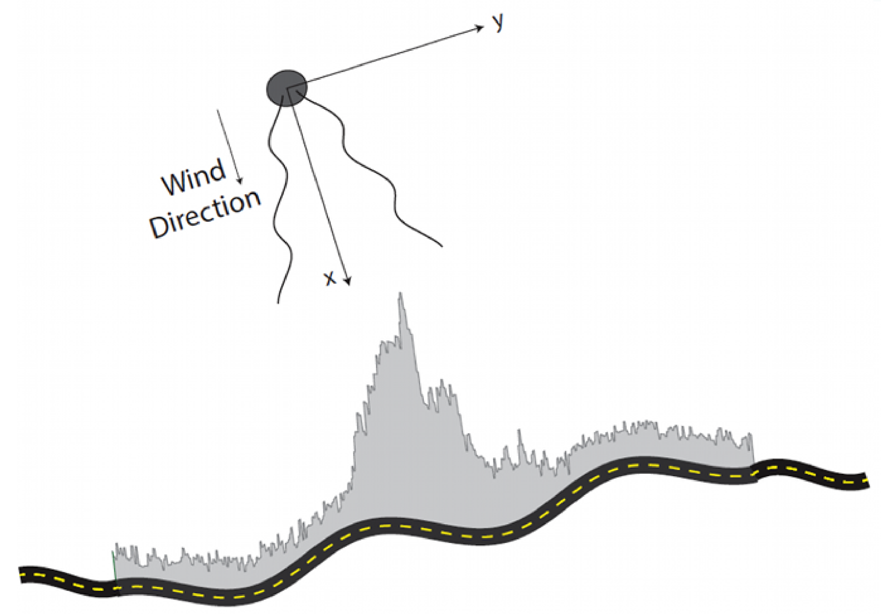


Figure 4: Gaussian shape along the crosswind axis (from [1])

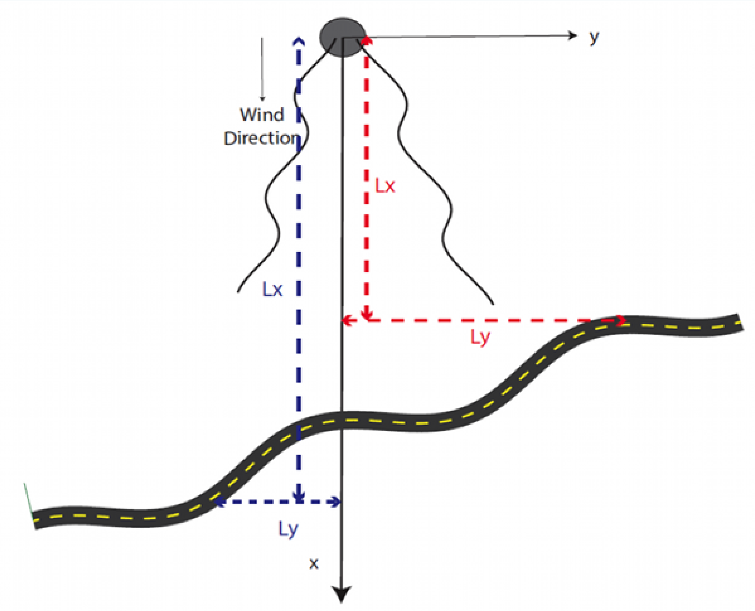


Figure 5: Calculation of Lx and Ly (from [1])

A Gaussian dispersion model was assumed, in which the dispersion along the crosswind axis Ly and the dispersion along the vertical axis Lz follow Gaussian shapes.

$$Y_{Lx,Ly,Lz,t} = S[(1/\bar{U})D_z D_y] + \epsilon$$

- $Y_{Lx,Ly,Lz,t}$ is the CH4 concentration (g/m^3) at location (L_x, L_y, L_z) at time t.
- S is the emission source rate (g/s) which we are trying to estimate.
- $\bar{U}$ is the mean windspeed along the downwind axis (L_x).
- L_x is the downwind distance from the source (m).
- L_y is the crosswind distance from the source (m).
- L_z is the vertical distance from the source (m).
- $D_y = \frac{1}{\sqrt{2\pi}\sigma_y} exp\left[-\frac{1}{2}\left(\frac{L_y}{\sigma_y}\right)^2\right]$ is the horizontal dispersion.
- σ_y^2 is estimated by approximating $Y_{Lx,Ly,Lz,t} = g(L_y)$ with a Gaussian function, by minimizing the sum of squared errors.
- D_z is the vertical dispersion. Estimates for these values were obtained from [1].
- Assumption: $\epsilon_t \overset{iid}{\sim} N(0, \sigma_e^2)$

Table 1: Variables used in the model.

Lap	$\bar{U}$	D_z	σ_y
1	7.55	0.08	3.98
2	7.29	0.08	4.41
3	4.48	0.07	5.47
4	5.96	0.07	3.24
5	8.65	0.08	4.47

Results

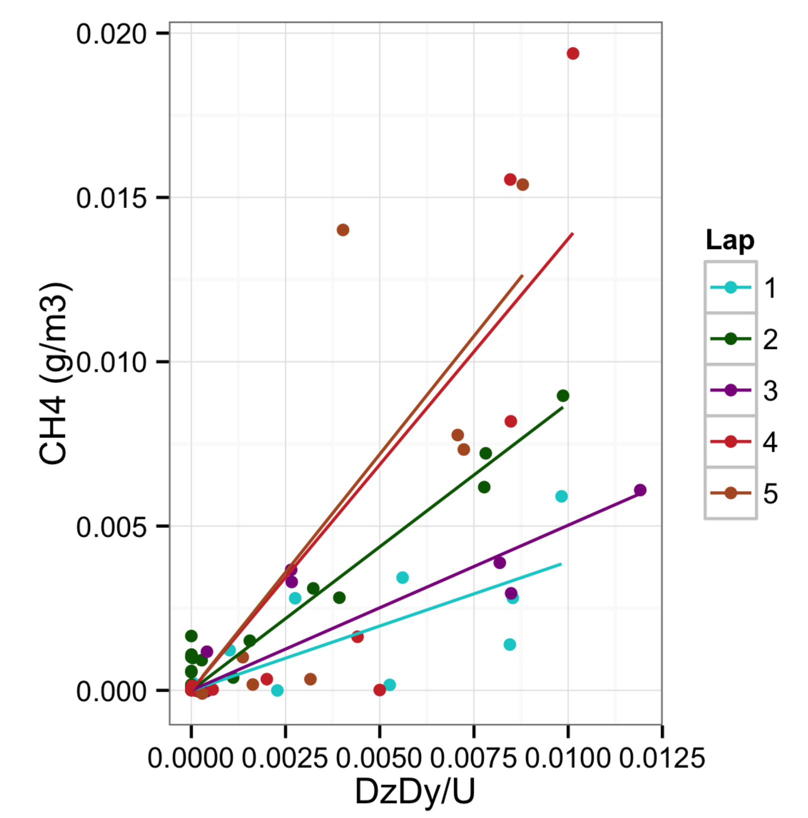


Figure 6: Slopes represent least squares source estimates.

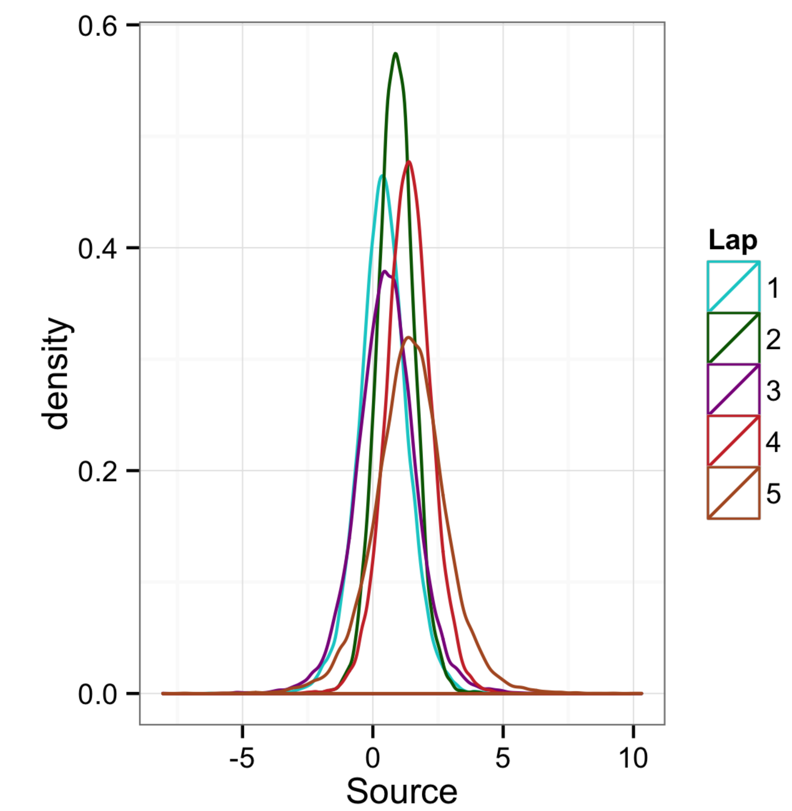


Figure 7: Constant prior (weak): $N(0.8, 100)$

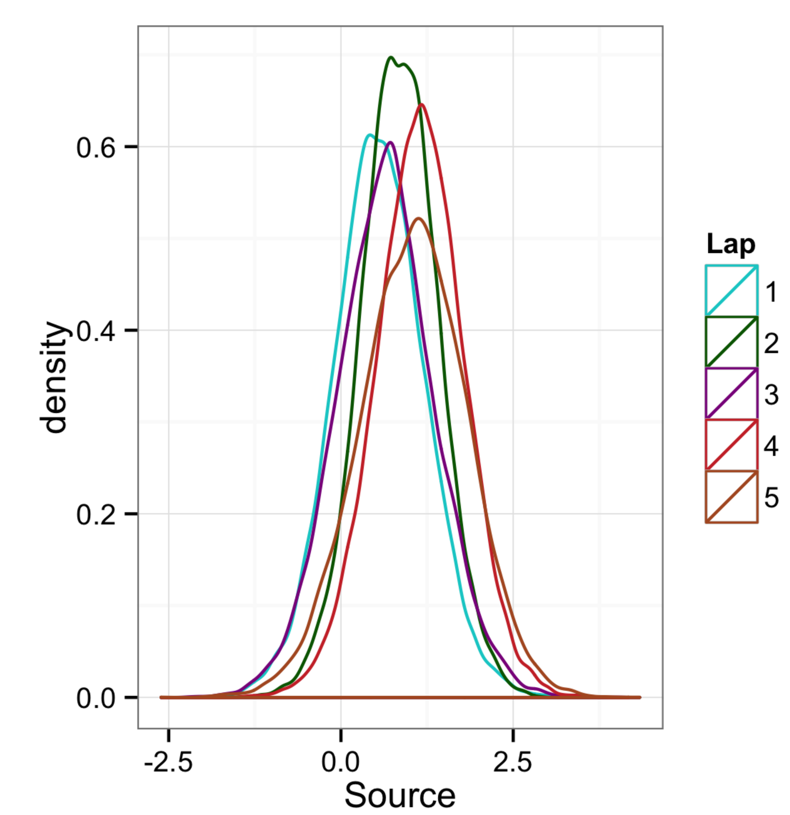


Figure 8: Constant prior (strong): $N(0.8, 1)$

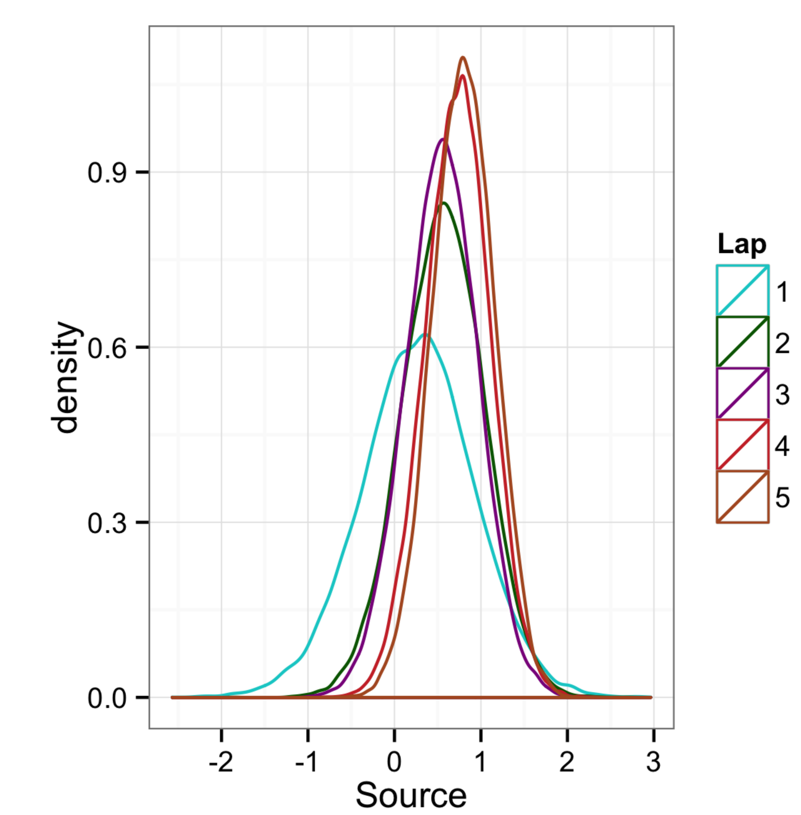


Figure 9: Updated prior (strong, too low): $N(0.1, 1)$

Table 2: Estimates of S (emission rate), the true value is approximately 0.8 g/s

	Least Squares		Constant Prior				Updated Prior	
			$N(0.8, 100)$		$N(0.8, 1)$		$N(0.1, 1)$	
	$\bar{S}_{LS}$	$SE(\bar{S}_{LS})$	$\bar{S}$	$SE(\bar{S})$	$\bar{S}$	$SE(\bar{S})$	$\bar{S}$	$SE(\bar{S})$
Lap 1	0.39	0.08	0.40	0.95	0.56	0.66	0.27	0.66
Lap 2	0.87	0.04	0.88	0.71	0.85	0.57	0.56	0.47
Lap 3	0.50	0.08	0.51	1.17	0.65	0.72	0.55	0.42
Lap 4	1.37	0.20	1.37	0.89	1.14	0.64	0.73	0.38
Lap 5	1.44	0.28	1.43	1.41	1.04	0.78	0.80	0.36

Conclusions

This analysis demonstrates that a Bayesian framework can be used to combine prior information about emission sources with concentration measurements from a mobile sensor, and wind measurements, to locate and quantify fugitive emissions from oil and gas production sites. The results have also demonstrated the importance of the choice of prior and ability of an updated prior to correct for an initially incorrect prior.

[1] Foster-Wittig, T.A. (2015) Chapter 5 Point source emission estimation from a single mobile sensor: a probabilistic approach. In T. A. Foster-Wittig Dissertation. [2] Albertson, J.D., Foster-Wittig T. A., Swingler, A., Federaro, S.F., Amin, S., Modrak, M., Brantley, H., Thoma, E. D. (2015) A mobile sensing approach for regional surveillance of fugitive methane emissions in oil and gas production. (manuscript in preparation). [3] U.S. EPA, Other Test Method (OTM) 33 and 33A Geospatial Measurement of Air Pollution-Remote Emissions Quantification-Direct Assessment (GMAP-REQ-DA). 2014. (http://www.epa.gov/ttn/emc/prelim.html).