A DISPERSION MODEL TO ESTIMATE CH_4 EMISSIONS FROM MANURE LAGOONS IN DAIRY FARMS

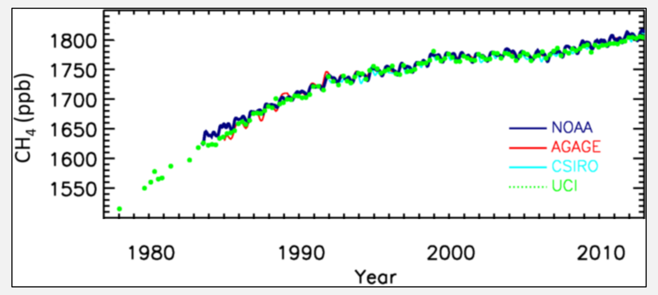
Ranga Rajan Thiruvenkatachari[1], Valerie Carranza[1], Faraz Ahangar[1], Alison Marklein[1,2], Francesca Hopkins[1], Akula Venkatram[1]

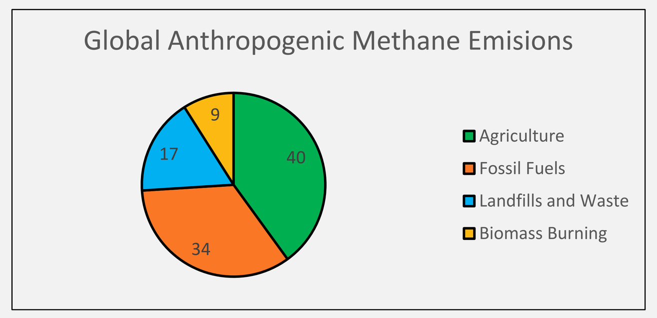
[1]University of California, Riverside, CA, 92521, USA

[2]Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA

MOTIVATION

- Global CH_4 emissions are now rising quicker than CO_2.
- 40% of global CH_4 emissions are from Agriculture.
- Manure management contributes to 17% of agriculture emissions in the US.
- National Academies of Sciences, Engineering (2018) report concludes that “fundamental research identifying and quantifying uncertainties is needed”.





STUDY REGION

- Manure Lagoons at a Southern California Dairy (SCD) and a Central California Dairy (CCD) were sampled.
- Preliminary analysis indicated that the lagoons highlighted in red had significant emissions and were modelled.
- 1066 milking cows at SCD while CCD had 3200.

Left: Aerial view of the lagoons in the Southern California Dairy, Right: Aerial view of the lagoons in the Central California Dairy

MEASUREMENT STRATEGY

- Mobile platform equipped with cavity ring-down spectrometer measured atmospheric CH_4.
- An inlet on the roof of the mobile platform was used to sample outside air.
- 3-D Sonic anemometer collected the meteorological inputs required for the dispersion model.
- Mobile platform was driven around the lagoons and stopped for ~10 minute intervals to collect CH_4 mixing ratios.

APPROACH TO ESTIMATE EMISSIONS

- The emissions are estimated from the dispersion model based on the following relationship:

$$C_j = C_b + \sum_i E_i T_{ij} + \varepsilon_j$$

From Dispersion Model

$$\textit{Minimise} \sum_j \varepsilon_j^2;\ E_i \geq 0 \text{ and } C_b \geq 0$$

Where, C_j - Concentration at the receptor j, C_b - Background Concentration, E_i - Emission Rate of source i, T_{ij} - Modeled impact at receptor j due to source i with unit emission rate and ε - Residual.

DISPERSION MODEL

- Manure lagoons are represented as a set of area sources whose contribution is the integral over a set of line sources perpendicular to the wind direction.
- Horizontal Distribution: Gaussian Formulation (Venkatram and Horst, 2006).

$$C(x_r, y_r) = \frac{q}{\sqrt{2\pi}} \int_{y_b}^{y_e} \frac{1}{\sigma_y (x_r - x)} e^{\left(-\frac{(y - y_r)^2}{2\sigma_y^2 (x_r - x)}\right)} dy$$

- Vertical distribution: Numerical solution of the mass conservation equation (Nieuwstadt and van Ulden.,1978)

$$U(z)\frac{\delta C}{\delta x} = \frac{\delta}{\delta z}\left(K(z)\frac{\delta C}{\delta z}\right)$$

q-Emission Rate/Length, σ_y-Horizontal Spread, σ_z-Vertical Spread, U-Wind Speed, C-Crosswind Concentration, K-Eddy Diffusivity

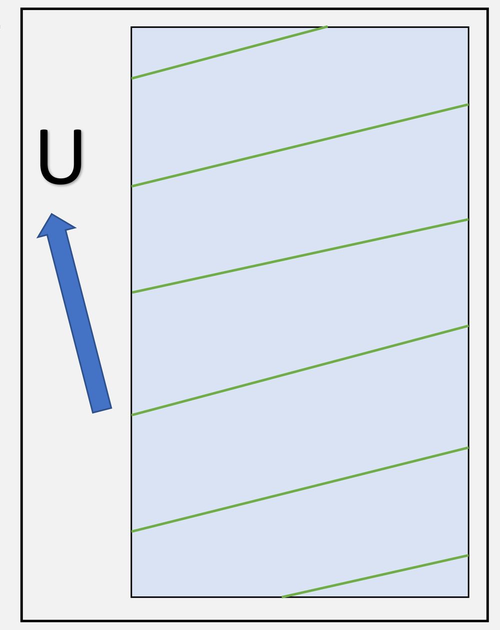
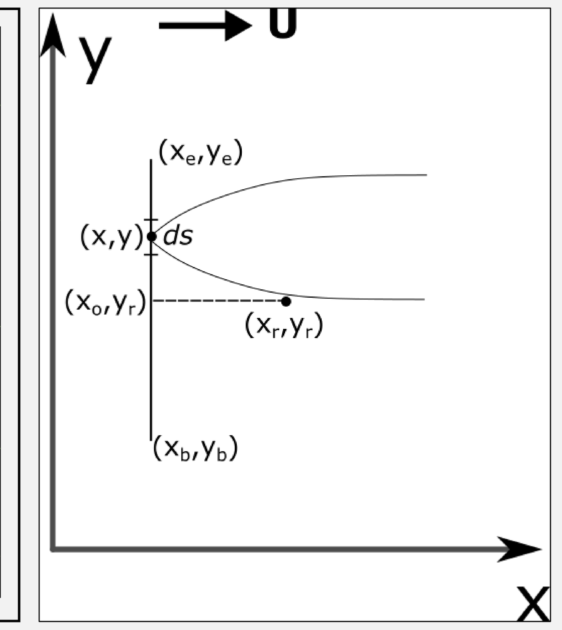
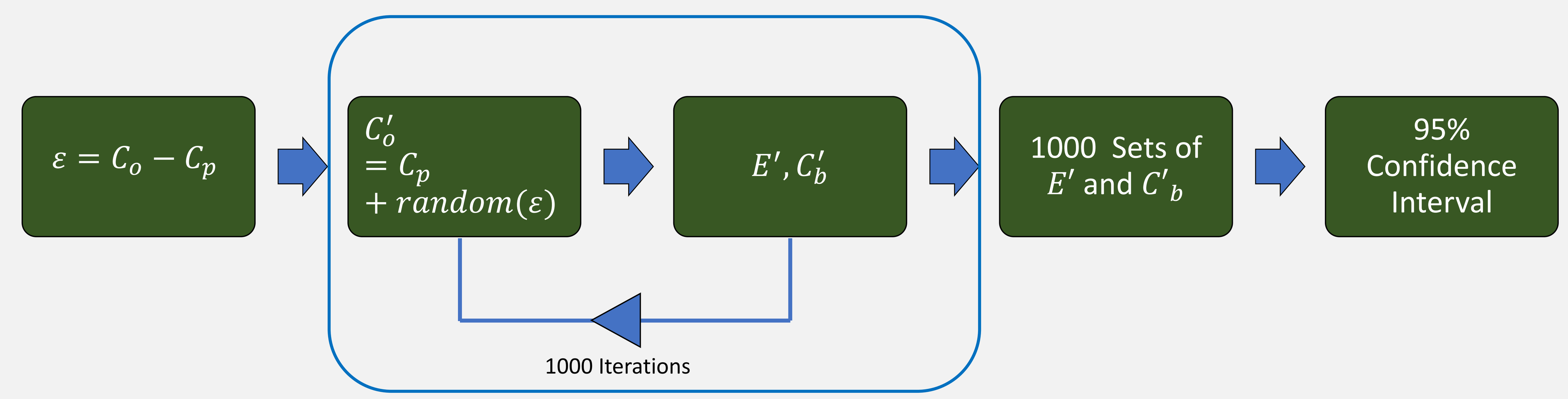


Illustration of an area source (blue) being represented as a set of line sources (green) perpendicular to wind direction.



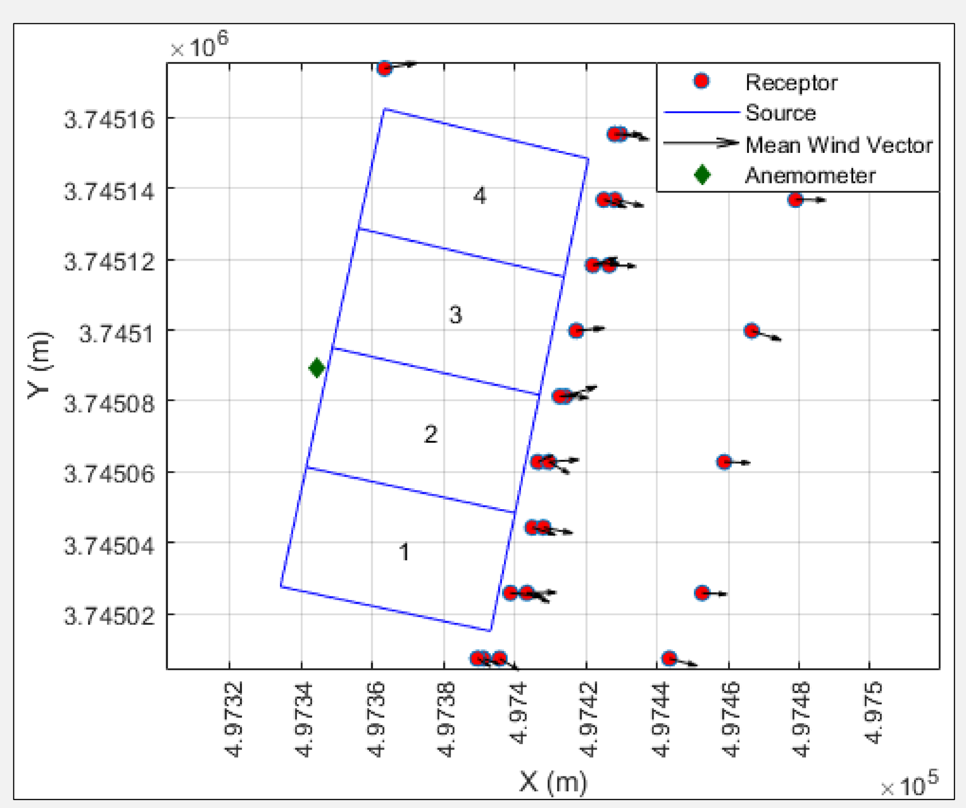
Co-ordinate system used to calculate the contribution of the point source (x, y) to the contribution at (x_r, y_r).

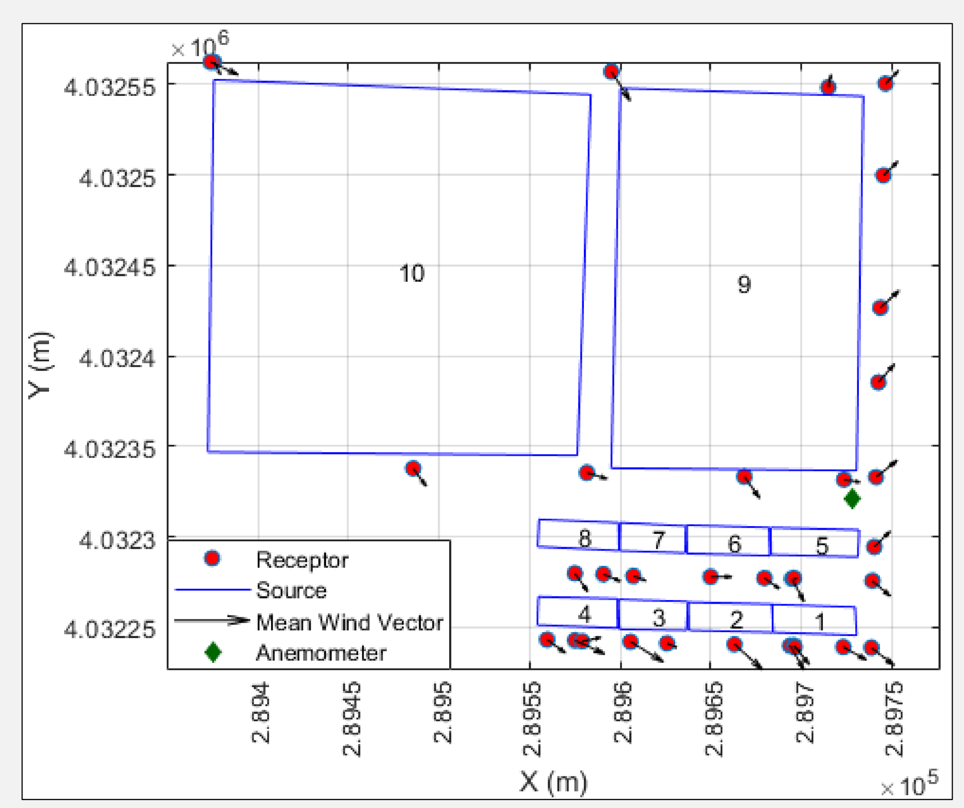
UNCERTANITIES THROUGH BOOTSTRAPPING



Where, C_o - Measured Concentration and C_p - Predicted Concentration

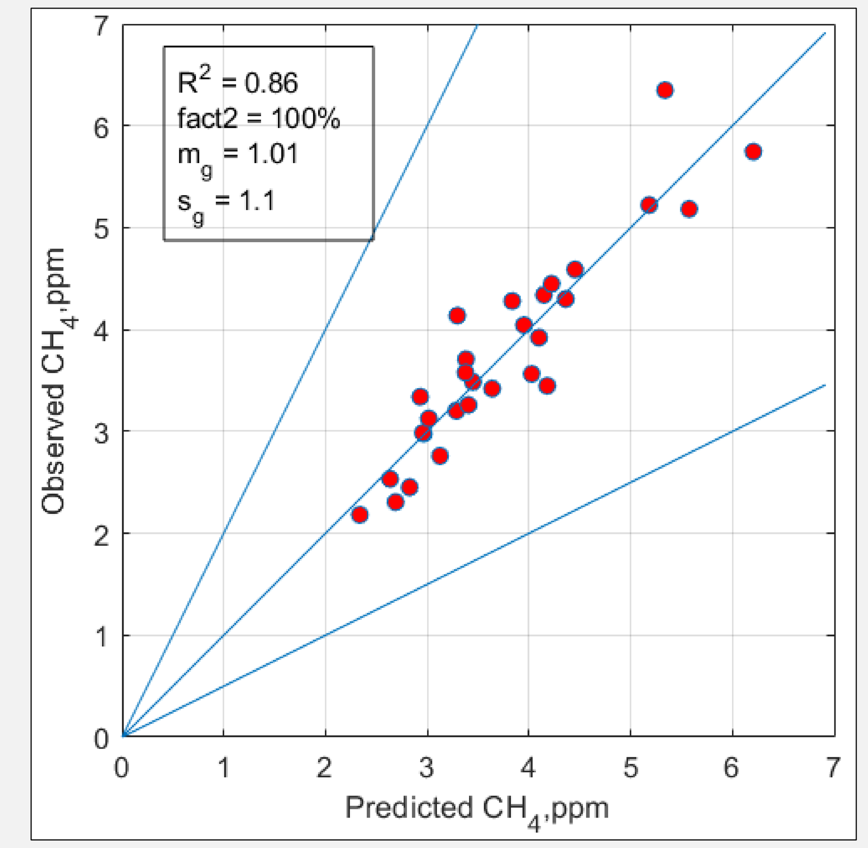
MODEL SETUP

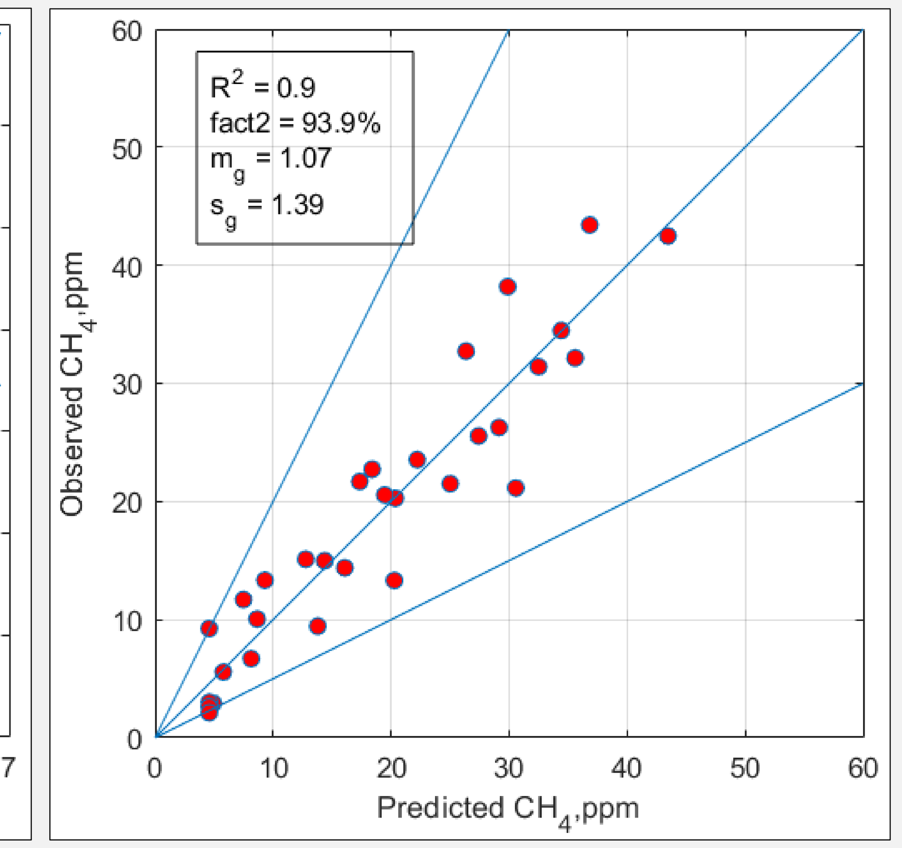




The left panel shows the source, receptor, anemometer location along with the mean wind vectors at the SCD while the right panel shows the same for CCD.

RESULTS





The left panel shows the scatter plot between predicted and observed concentration from the SCD while the right panel shows the same for CCD. The lines around the one-to-one line enclose model estimates within a factor of two of the measurements.

Table. *Inferred Emission Rates and Background Methane Concentration*

	Emissions		Fraction of 95% CI to Best Fit Emissions			
	SCD	CCD	SCD		CCD	
	kg/d	kg/d	Lower Limit	Upper Limit	Lower Limit	Upper Limit
Source 1	42	2080	0.19	1.84	0.82	1.19
Source 2	56	1481	0.59	1.44	0.70	1.31
Source 3	92	71	0.71	1.33	0.00	6.43
Source 4	203	253	0.82	1.20	0.00	6.40
Mean Total	396	3922	0.75	1.23	0.82	1.39
Back Ground (ppm)	2.34	4.58	0.83	1.19	0.51	1.44

CONCLUSIONS

- Sources that contribute the maximum to the total emissions have the least uncertainty.
- The predicted background concentration of 2.34 and 4.58 ppm is close to the measured background of 1.9 ppm and 4 ppm respectively for SCD and CCD..
- Farm-level calculations according to CARB inventory methodology predicts emissions of 334 kg/d and 1712-2952 kg/d respectively for SCD and CCD which are close to the model predictions.
- The methodology demonstrated can be applied to any emission source of similar scale and surface expression.
- Because the technique is rapidly deployable, use of it over multiple times of the days and seasons will help understand the temporal drivers of emissions.
- This method provides uncertainty estimates for emissions.

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