A Dispersion Model to Estimate CH_4 emissions from Manure Lagoons in Dairy Farms

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Abstract

Atmospheric concentrations of CH4 have tripled since the Industrial Revolution. One culprit of this increase is animal agriculture, contributing 8 to 10% of global greenhouse gas emissions primarily in the form of CH4. According to US Environmental Protection Agency greenhouse gas inventory estimates, the majority of the manure emissions are from manure management on dairy farms (53%). Most of these manure emissions are generated from liquid manure in anaerobic lagoons. Thus, accurate estimates of the emissions from these lagoons are essential for developing management strategies to reduce CH4 emissions. Emissions of methane from two manure lagoons, one in Southern California and the other in Central California, were estimated by fitting results from a state-of-the-art dispersion model to CH4 concentrations measured with a mobile monitor. The sampling was conducted by stationing the mobile monitors at several locations (29-42) around the lagoons for time intervals ranging from 10 to 15 minutes. A sonic anemometer provided micrometeorological measurements used by the dispersion model. Emissions were computed by fitting the time-averaged methane concentrations to model estimates. The 95% confidence intervals for the emissions were computed by bootstrapping pseudo observations created by adding residuals between model estimates and corresponding observations to the best fit model estimates. The coefficient of determination, r2, between model and measurements made at the Southern California dairy was over 0.86 and the geometric standard deviation (sg) was 1.1; the steady westerly wind direction was a major factor for this result. At the Central California dairy, the winds were light and variable resulting in an r2 of about 0.9 and a high sg of 1.4. The sensitivity of the emission estimates to wind direction was determined by running the dispersion model for different wind sectors. We found that the emission estimates were within 1.5 times of each other under all wind conditions. The dispersion model was cross-validated by estimating the emissions using only half the total receptors and then predicting the concentration at other receptors using this emission rate. This technique can be used to improve methane emission estimates in manure management and to assess the effectiveness of the different strategies to reduce emissions.

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

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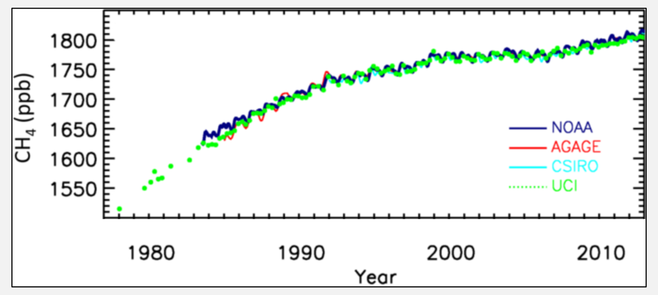
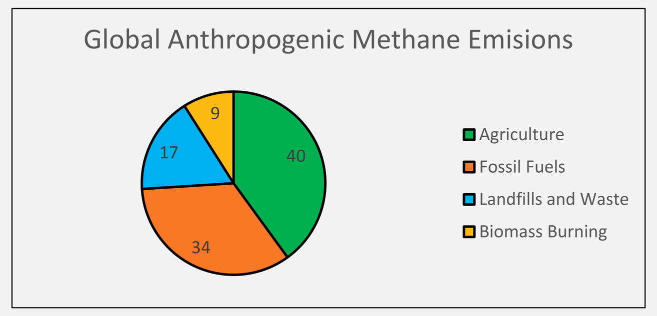
MOTIVATION

- 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

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

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

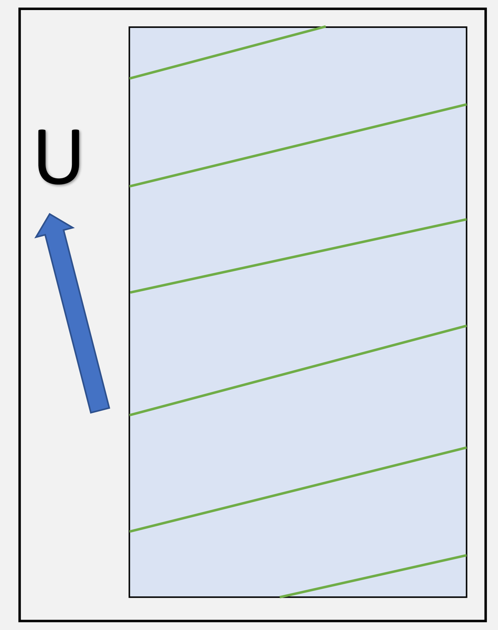
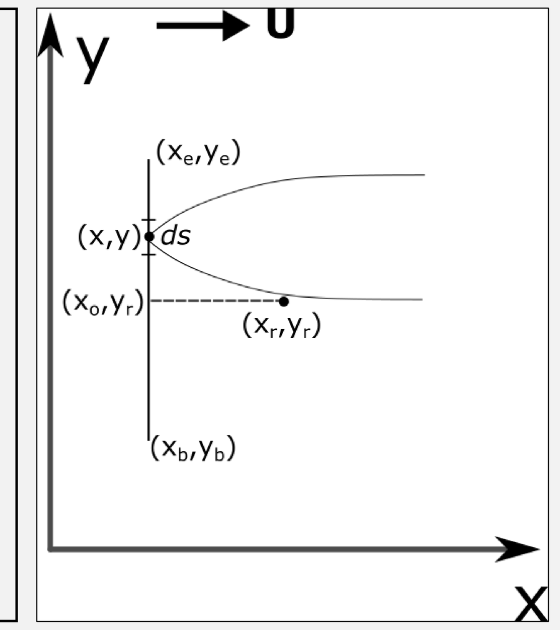
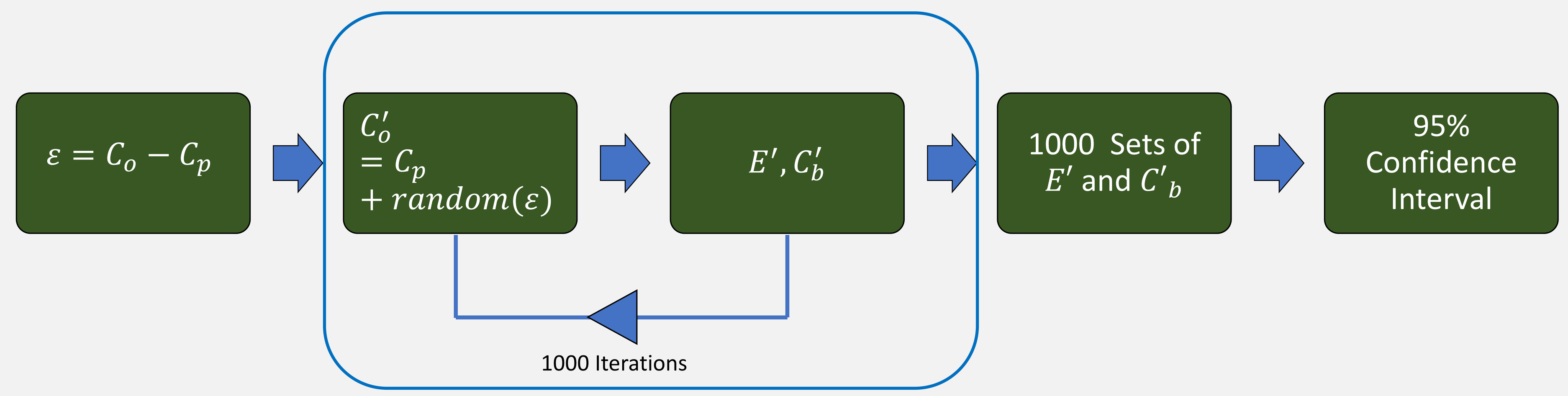


Illustration of an area source (blue) being represented as a set of line sources (green) perpendicular to wind direction.



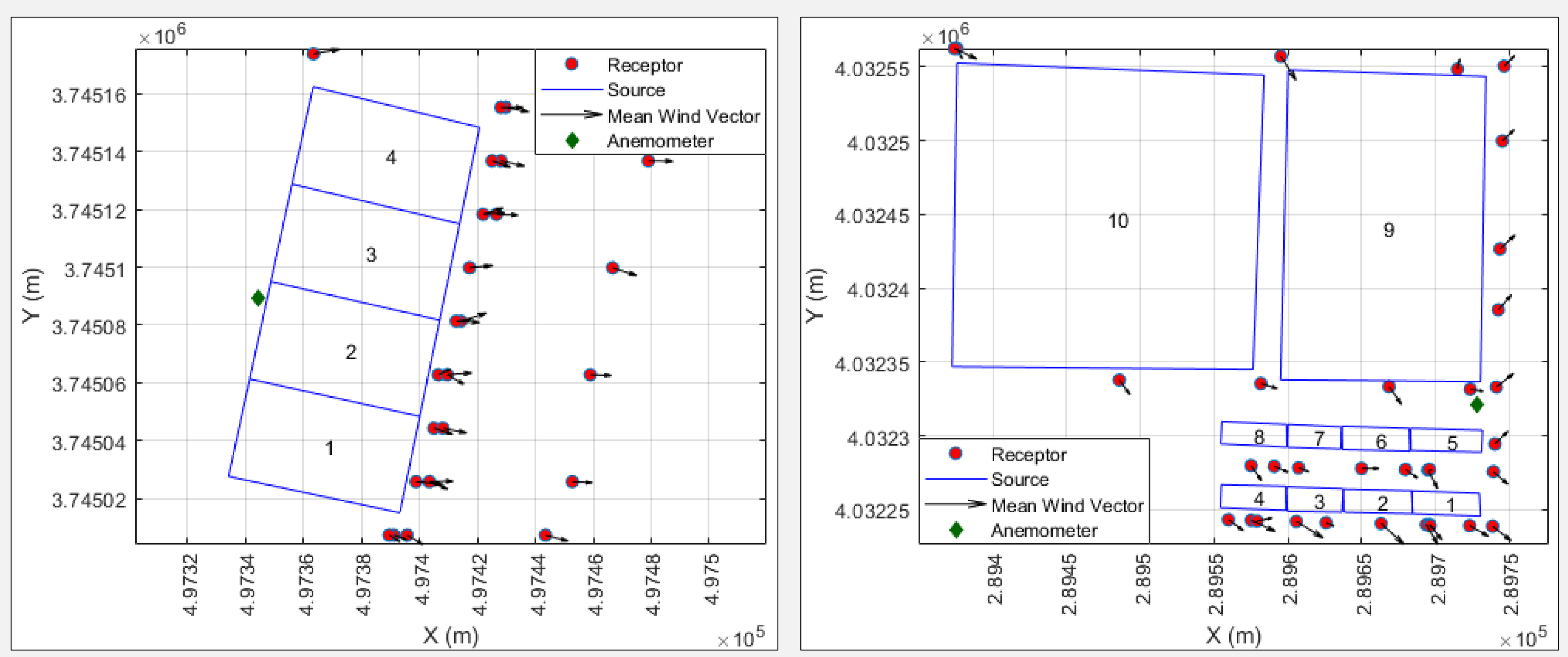
Co-ordinate system used to calculate the contribution of the point source (x, y) to the contribution at (x_r, y_r).

UNCERTANITIES THROUGH BOOTSTRAPPING



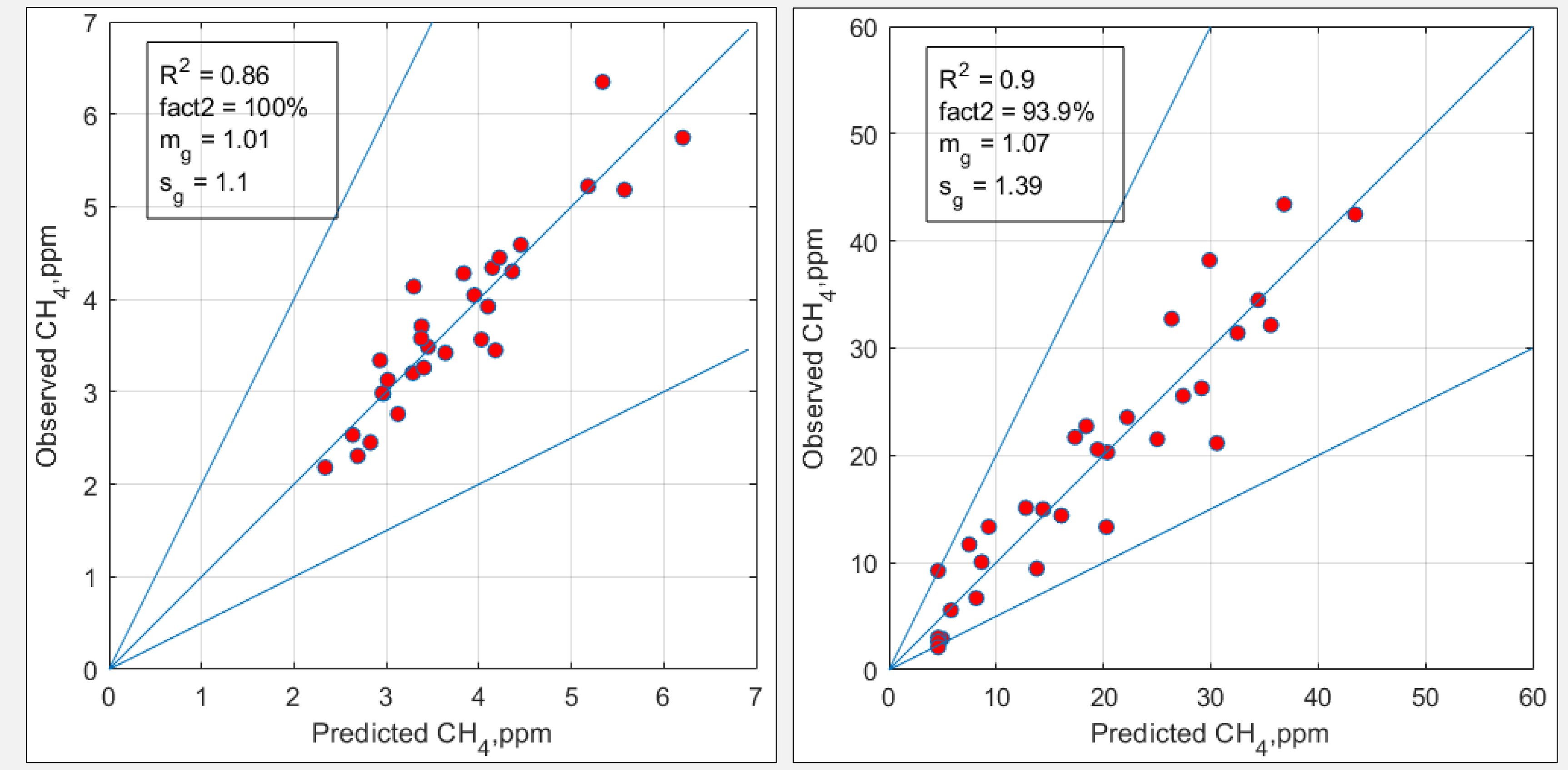
Where, C_o - Measured Concentration and C_p - Predicted Concentration

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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