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METHANE EMISSIONS FROM A NEW MEXICO DAIRY LAGOON SYSTEM

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ABSTRACT

Methane is a greenhouse gas with a global warming potential twenty-five times that of carbon dioxide. Animal production is recognized as a significant source of methane to the atmosphere. Dairies on the southern High Plains of New Mexico and Texas are typically open lot, and major sources of methane are enteric emissions from cattle and wastewater lagoons. Uncovered anaerobic lagoons are identified by the U.S. Environmental Protection Agency as a major source of methane in dairy manure management systems. Our objective was to quantify methane emissions from the wastewater lagoons of a commercial dairy located in eastern New Mexico. Research was conducted during six days in August, 2009 at a 3500-cow open lot dairy with flush alleys. Methane concentration over three interconnected lagoons (total area 1.8 ha) was measured using open path laser spectroscopy. Background methane concentration was measured using a back-flush gas chromatography system with flame ionization located upwind in the direction of prevailing winds. Wind and turbulence data were measured using a three-axis sonic anemometer. Emissions were estimated using an inverse dispersion model. Methane concentration over the lagoons ranged from 3 to 12 ppm, and averaged 5.6 ppm; background methane concentration averaged 1.83 ppm. Methane flux density ranged from 165 to 1184 $\mu g\ m^{-2}\ s^{-1}$. Mean daily methane flux density was 402 kg $ha^{-1}\ d^{-1}$. Per capita methane emission rate averaged 0.211 kg $head^{-1}\ d^{-1}$. Uncovered anaerobic lagoons were a significant source of methane emitted from this southern High Plains dairy, and lagoons could be a significant control point for emission reduction.

KEYWORDS. methane, methane emission, greenhouse gases, dairy wastes, waste water, manure management systems, micrometerology, laser spectroscopy, inverse modeling.

INTRODUCTION

Methane is second to carbon dioxide in atmospheric radiative forcing, providing about 20% of the positive radiative forcing of long-lived greenhouse gases (IPCC, 2007). Though present in the atmosphere at relatively low concentration (~1.8 ppm), its global warming potential is 25 times that of carbon dioxide over 100 years. Methane concentration almost tripled from its pre-industrial concentration of 0.7 ppm. Then, beginning in the mid-1980s the rate of increase of atmospheric methane decreased to near zero during 2000-2006 (Steele et al., 1992; Bousquet et al., 2006) . However, since 2007 this trend has reversed and methane concentration has increased about 7 ppb yr^{-1} (Rigby et al., 2008).

Methane comprised 9.6% of U.S. carbon dioxide equivalent (CO_2e) greenhouse gas emissions in 2007 (EIA, 2008). Major sources of methane emitted to the atmosphere in the U.S. greenhouse gas inventory include fossil fuel energy production systems (39%), landfills (24%), enteric fermentation by ruminant livestock (20%), and animal waste (9%). USDA (2008) estimated that dairy cattle were responsible for 20% of the 259 Tg of livestock CO_2e emissions in 2005, second to beef cattle (65%). Dairy cattle emitted 25% of enteric methane emissions, and 46% of methane from managed livestock waste (USDA, 2008). Managed waste is manure (feces and urine) that is stored or treated or spread on fields. Examples of storage systems include dry lots, liquid-slurry storage, deep pit storage, and anaerobic lagoons.

The U.S. Environmental Protection Agency (EPA, 2009) ruled that livestock facilities with manure management systems (MMS) that emit more than 25000 Mg $CO_2e\ yr^{-1}$ were required to report emissions of the greenhouse gases methane and nitrous oxide. Manure management systems include uncovered anaerobic lagoons, liquid/slurry systems, solid manure storage, and dry lots. The threshold for dairies to report is an average annual animal population of 3200 head. Although

the MMS portion of the mandatory greenhouse gas reporting rule is not currently in force because Congress prohibited the expenditure of funds to implement it, accurate and comprehensive data on greenhouse gas emissions from dairies are needed for potential regulatory demands, and for national and international greenhouse gas inventories.

Our objective was to quantify methane emissions from an uncovered anaerobic wastewater lagoon at a commercial dairy typical of those in operation on the southern High Plains of New Mexico and Texas.

MATERIALS AND METHODS

Research Site and Dairy Management

Research was conducted from 8Aug09 to 15Aug09 at a commercial dairy located in Curry County, New Mexico, typical of dairies in eastern New Mexico and west Texas (Figure 1). Cows were housed in open lot soil/manure-surfaced corrals, with total area of 22.5 ha. Each corral (from 82- to 96-m x 225-m) was equipped with a 7-m x 192-m sun shade. Feed lanes were surfaced with concrete, and were flushed periodically to remove accumulated manure. Flushed effluent entered a 700-m long canal that flowed into the lagoon system.

The lagoon system consisted of four lagoons. During the study, the first three lagoons (1.8 ha surface area) contained effluent; the fourth lagoon was dry. Solids were separated from flushed effluent before it entered the lagoons and were stockpiled near the separator. An aerator operated intermittently near the inlet of the first lagoon. The first lagoon (east) was connected to the second (west) by a 2-m wide surface channel; the third lagoon (south) normally received effluent pumped from the first lagoon. Water from the lagoon system was periodically pumped to the north end of the dry lot and recycled as flush water.

The dairy was populated with almost 3500 cows; 73% were milking cows (150 days), 7% were fresh cows (20 days), and 20% were dry cows (Table 1). Dry matter intake (DMI) averaged 25.1 and 21.5 kg head^{-1} d^{-1} and crude protein (CP) was 16.73 and 17.45% of DMI for milking and fresh cows, respectively. During the study period, milk production averaged 29.2 kg milk head^{-1} d^{-1}.

Table 1. Cow population and composition of key feed ration components.

Cow type	Population	Dry Matter Intake (DMI)	Estimated net energy	Crude protein (CP)	Neutral detergent fiber	Acid detergent fiber	Fat
	head	kg head^{-1} d^{-1}	Mcal	----------	% DMI	----------	
Milking	2541	25.1	39.5	17.45	34.74	21.19	4.7
Fresh	261	21.5	31.34	16.73	38.43	23.25	3.9
Dry (close-up)	168	13.4	16.02	15.17	41.88	31.14	2.1
Dry (far-off)	522	13.5	18.5	13.58	35.72	22.62	3.0

Micrometeorological Measurements and Flux Quantification

Methane concentration at the lagoons was measured using an open path tuned diode laser (Gasfinder 2.0, Boreal Laser, Inc., Spruce Grove, AB, Canada[1]) deployed at a height of 1.65 m. Prevailing wind direction was southerly, so the laser path was positioned either along the north side of the lagoons (DOY 219-223, path length 233 m) or diagonally from northeast to southwest across the lagoons (DOY 224-227, path length 239 m) (Figure 1). The laser path was changed during the morning of DOY 224 to include easterly winds. The laser measured methane concentration every 35 s. The open path laser was calibrated in the laboratory after completion of

[1] Mention of trade names or commercial products is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture.

the study and a calibration factor of 1.26 used to adjust measured concentration. Background methane concentration was measured at a location 75 m south of the southwest corner of the open lot corrals and 680 m west of the lagoons using a back-flush gas chromatography system with flame ionization, with a minimum detection limit of 0.05 ppm (Model 55I, Thermo Scientific, Waltham, MA). Background methane concentration was measured once a minute and 15-min averages calculated. The background methane system was calibrated periodically on site. The locations of the open path laser and background measurement constrained acceptable wind directions to between 100° and 270° because of possible contamination of methane concentration measurements by methane emissions from the open lot.

Wind and turbulence data were measured using a three-axis sonic anemometer (Model 81000, R.M. Young, Traverse City, MI). The sonic anemometer was located about half way along the north side of the lagoon system at a height of 3.8 m. Data were sampled at 10 Hz frequency and 15-min means, variances and covariances of sonic temperature, and with-wind, cross-wind and vertical velocities were stored on a datalogger (CR21X, Campbell Scientific, Inc., Logan, Utah). Coordinate rotations were employed and wind direction, wind speed (u), friction velocity (u*), turbulence statistics (σ_u, σ_v, σ_w), sonic air temperature, sensible heat flux, roughness length and Monin-Obukhov length (L) were calculated.

Methane emissions from the lagoons were quantified using an inverse dispersion model (Windtrax 2.0.7.9, Thunder Beach Scientific, Nanaimo, BC, Canada). The methodology is comprehensively discussed in Flesch and Wilson (2005). Gas concentration downwind of an emission source area is coupled with upwind concentration (background), wind information, and a map of the source area to estimate the emission rate by calculating the emission rate necessary to cause the measured increase in concentration. The inverse dispersion model assumes that the atmospheric surface layer is homogeneous, that flow is stationary and that the source strength is spatially uniform. Harper et al. (2009) reported that BLS flux estimates from several studies ranged from -14% to +7% of known tracer releases. Gao et al. (2009), using open path lasers, found that BLS overestimated methane flux by 9%. The lagoon source area was mapped using geographic coordinates taken from a georeferenced digital orthophoto quadrangle of the dairy (MrSID Geoviewer 2.1, LizardTech, Inc., Seattle, WA). Model runs were executed on input data sets with 15-min time steps using ensembles of 10000 particles. Data were excluded from input data sets when any of these conditions were met: $u^* < 0.15$ m s^{-1} $|L| < 10$ (extreme atmospheric stability or instability), or wind direction was greater than 270° or less than 100°.

RESULTS AND DISCUSSION

General Conditions and Data Retention

The first three days of the study were warm with southerly winds (Table 2). A thunderstorm during the evening of DOY 222 rained 29 mm in less than two hours. Runoff from the dry lot filled the two north lagoons and overflowed the berm into the south lagoon. Subsequent days had variable wind directions and tended cooler and with greater humidity than before the rain. Another rain during the morning of DOY 224 totaled 2.3 mm. After applying data quality criteria, 389 out of 768 15-min observations (51%) were accepted for analysis.

Table 2. Mean daily meteorological conditions during study. Values are means of 96 15-min observations for each day, except DOY 227, which has only 33 observations from the morning. The σ_u, σ_v, and σ_w are standard deviations of the wind velocity fluctuations, u* is the friction velocity, and z_0 is the roughness length.

DOY	Air temperature	Relative humidty	Wind speed	Friction velocity	σ_u/u^*	σ_v/u^*	σ_w/u^*	z_0
	C	%	m s^{-1}	m s^{-1}				m
220	27.6	36	3.27	0.42	2.36	2.09	1.07	0.08
221	26.0	44	4.21	0.47	2.35	1.96	1.11	0.08
222	23.5	59	3.43	0.39	2.64	2.38	1.10	0.07
223	24.0	63	2.49	0.27	2.56	2.46	1.17	0.07
224	23.8	63	2.50	0.30	2.45	2.52	1.08	0.08
225	23.8	62	3.34	0.33	2.20	2.09	1.12	0.07
226	22.1	74	2.97	0.37	2.31	2.11	1.09	0.08
227	18.0	93	1.64	0.17	2.31	2.11	1.06	0.08

Methane Concentration and Flux

Background methane concentration averaged 1.829± 0.175 ppm during the study. Methane concentration at the lagoons ranged from 3 to 12 ppm (Figure 2). Greatest concentration (>10 ppm) was observed either near sunrise or during stable nighttime periods. Mean daily methane concentration at the lagoons was 5.6 ppm. Typically, concentration rose at sunrise to a daily maximum of around 8 ppm, and then decreased to between 4 and 6 ppm for most of the day (Figure 3).

Methane flux ranged from 170 to 1190 µg m^{-2} s^{-1} (Figure 4). Daily minima tended to occur during the afternoon. An exception was on DOY 223, when afternoon flux densities exceeded 700 µg m^{-2} s^{-1}. These higher flux densities occurred on the day following the 29 mm rain and large influx of water into the lagoons. A diel composite (n = from 2 to 6 for each 15-min) showed methane flux minima (~300 µg m^{-2} s^{-1}) around 0300 and 0900 (Figure 5). Mean maximum flux density (~650 µg m^{-2} s^{-1}) occurred 90 min either side of sunrise. Ding et al. (2004) reported that diel methane emissions from a freshwater marsh peaked 4 hr after sunrise and then decreased as oxygen from plant photosynthesis accumulated. The diel pattern in Figure 5 is suggestive of this effect, and daytime dissolved oxygen in lagoon water tended to be greater during daytime than nighttime (0.68 mg L^{-1} vs. 0.57 mg L^{-1}). Mean daily methane flux density was 402 kg ha^{-1} d^{-1}. On a per capita basis, methane emission averaged 0.21 kg $head^{-1}$ d^{-1}.

Methane emissions from anaerobic lagoons range widely. Khan et al. (1997), using the integrated horizontal flux method, found that methane flux from a New Zealand dairy slurry pond ranged from 2 to 148 µg m^{-2} s^{-1}; daily emission rate for two days averaged 9.75 kg ha^{-1} d^{-1}, compared with this study's much larger value of 402 kg ha^{-1} d^{-1}. However, these data were collected during winter and temperature was about half that observed during our study. Safley and Westerman (1992) found that a covered anaerobic dairy lagoon managed for biogas production produced 0.147 m^3 CH_4 m^{-2} d^{-1} over 17 months, with a peak production of 0.52 m^3 CH_4 m^{-2} d^{-1}. Mean volumetric methane flux in this study was 0.057 m^3 CH_4 m^{-2} d^{-1} (0° C, 100 kPa), 39% of the methane production measured by Safley and Westerman (1992). Sutter and Ham (2005) collected biogas emitted over 1 yr from a swine lagoon. Methane flux density annually averaged 136 µg m^{-2} s^{-1}; a peak flux of 2431 µg m^{-2} s^{-1} occurred in June. Park et al. (2010) reported methane flux from liquid swine manure in a tank of 1650 µg m^{-2} s^{-1}. In contrast, Sharpe and Harper (1999) found much lower emissions from swine lagoons, ranging from 52 µg m^{-2} s^{-1} during winter to 70 µg m^{-2} s^{-1} during summer. Even lower emissions reported by Sharpe et al. (2002) using a flux-gradient method were probably attributable to limited fetch.

Sharpe et al. (2002) found that methane emission from a swine lagoon was positively correlated with wind speed. However, methane emission from the lagoons in this study was inversely

correlated with wind speed (Figure 6). Methane is produced in anoxic conditions near the bottom of the lagoons and ebulliently transferred to the surface. Le Mer and Roger (2001) in a comprehensive review of methane research, reported on several rice paddy studies where from 70% to >90% of methane was reoxidized by methanotrophs as methane rose through the water column and encountered aerobic conditions. Greater wind speed could aerate a deeper column of water and methanotrophic activity increase, which would reduce methane emissions and account for the inverse relationship between wind speed and methane flux we observed.

We used the EPA greenhouse gas inventory methodology to estimate methane emission from the lagoon system. We partitioned the dairy's manure equally between dry lot, solid storage and uncovered anaerobic lagoon and assumed a dairy population of 2800 dairy cows and 700 dairy heifers; all other parameters in the inventory model were left unchanged. The inventory model estimated methane emission rate from the uncovered anaerobic lagoon to be 704 kg d^{-1}. Mean methane emission rate measured in this study over 7 days was 737 kg d^{-1}. This agreement is possibly fortuitous, considering the general nature of the inventory method and that we have not quantified how manure at this dairy is actually partitioned. However, it does lend evidence that wastewater lagoons are significant sources of methane from dairy manure management systems and could be a significant control point for methane emission reduction.

CONCLUSION

Methane emissions from an anaerobic wastewater lagoon system at a commercial New Mexico dairy were quantified during 7 days in August 2009 using open path laser spectroscopy and an inverse dispersion model. Methane concentration at the lagoons ranged from 3 to 12 ppm and averaged 5.6 ppm. Methane fluxes ranged from 170 to 1190 µg m^{-2} s^{-1}. Mean daily methane flux was 402 kg ha^{-1} d^{-1}, and on a per capita basis, emission rate was 0.21 kg $head^{-1}$ d^{-1}. These values tended to fall in the middle of the range of methane emissions from anaerobic animal waste lagoons reported in the literature. Further research is needed into the factors that affect methane emissions from wastewater lagoons, such as lagoon chemistry, manure partitioning, volatile solids loading, and temperature dependency. Measurement of methane emissions throughout the year is needed to account for intra-annual variability.

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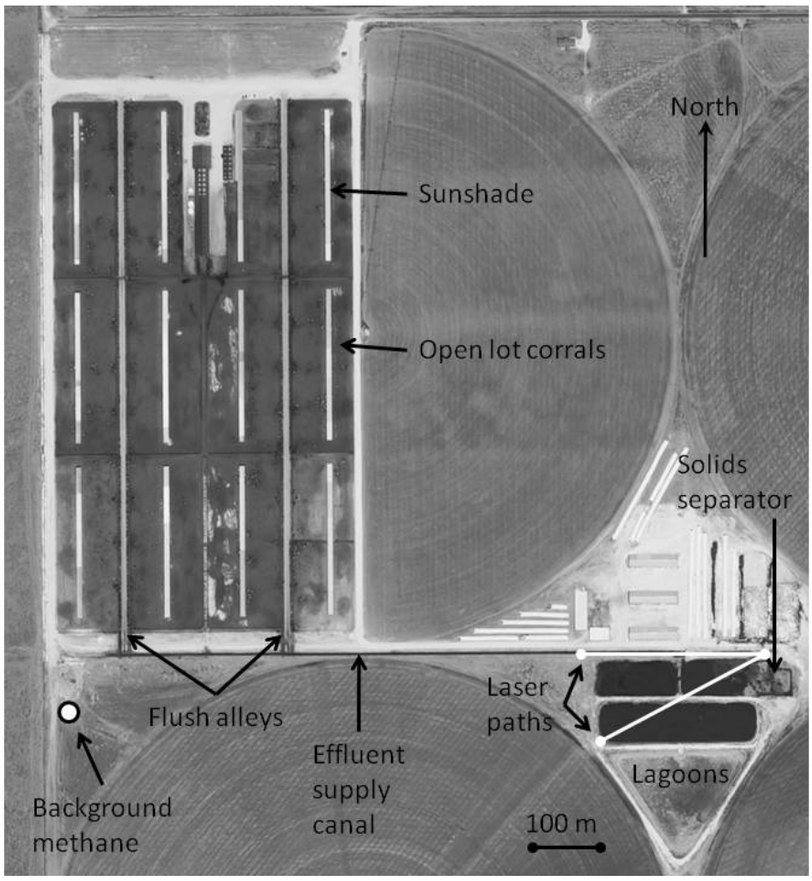

Figure 1. Commercial dairy used in study. Area of open lot corrals was 22.5 ha and area of the three lagoons with effluent was 1.8 ha.

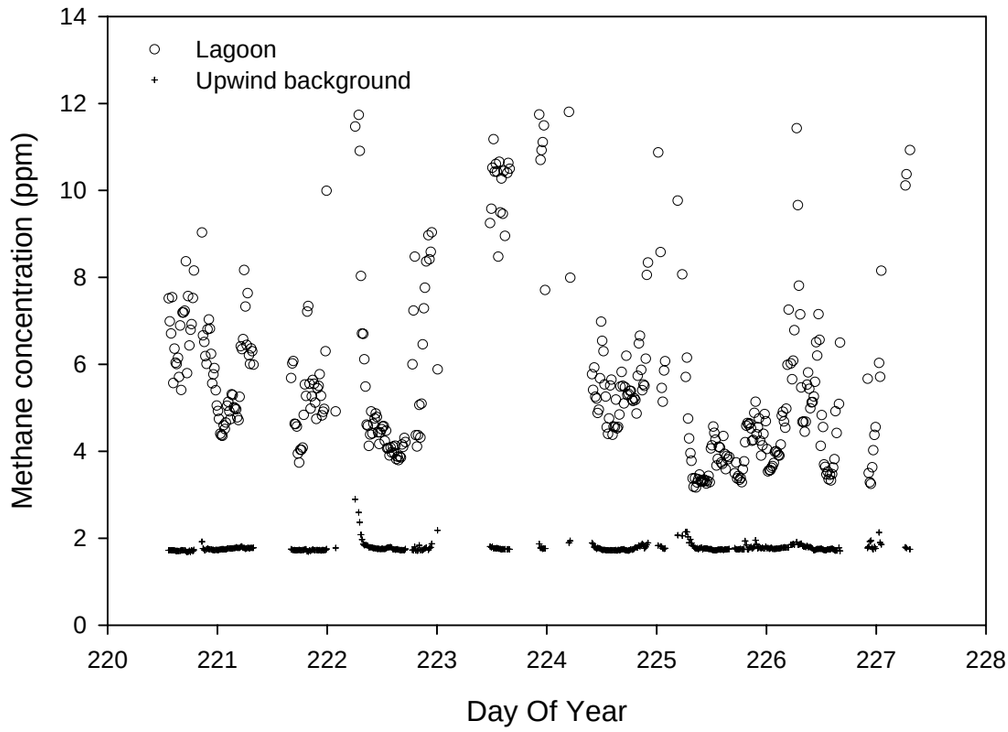

Figure 2. Mean 15-min atmospheric methane concentration at the lagoons and upwind background concentration.

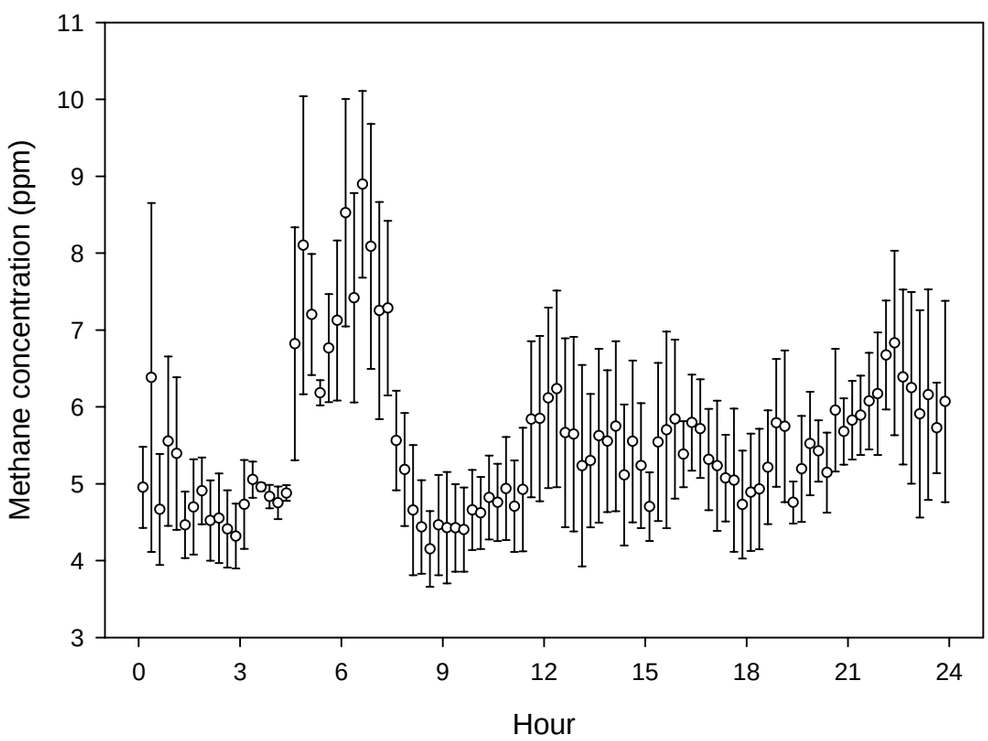

Figure 3. Composite diel methane concentration at lagoons. Error bars are the standard error for each 15-min mean.

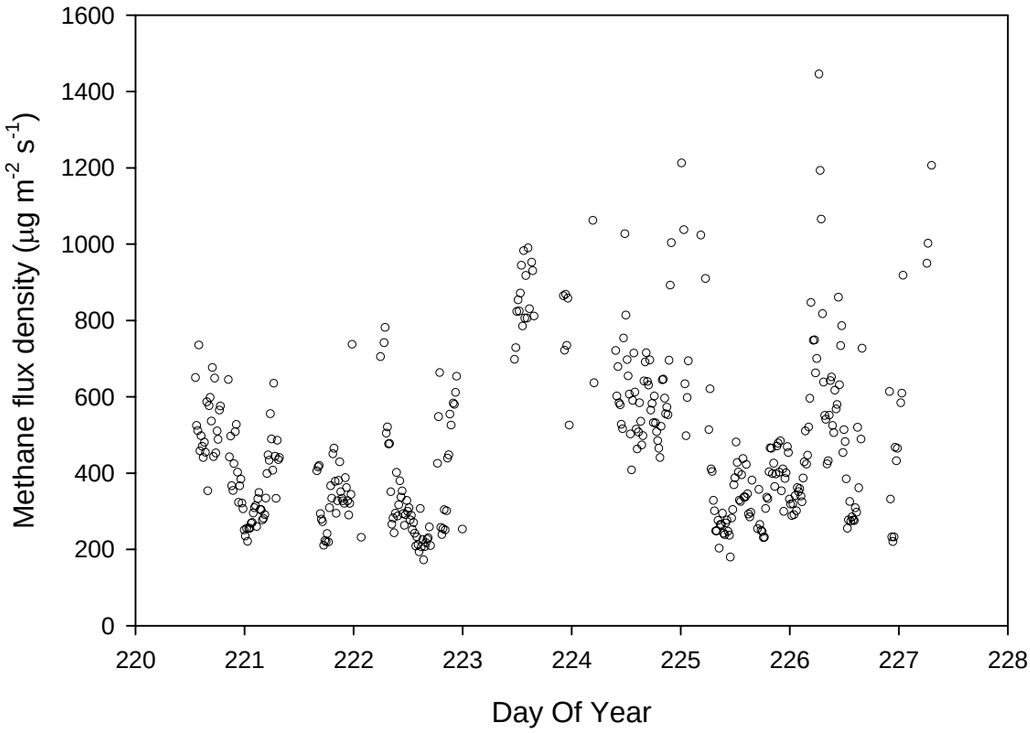

Figure 4. Mean 15-min methane flux density from lagoons.

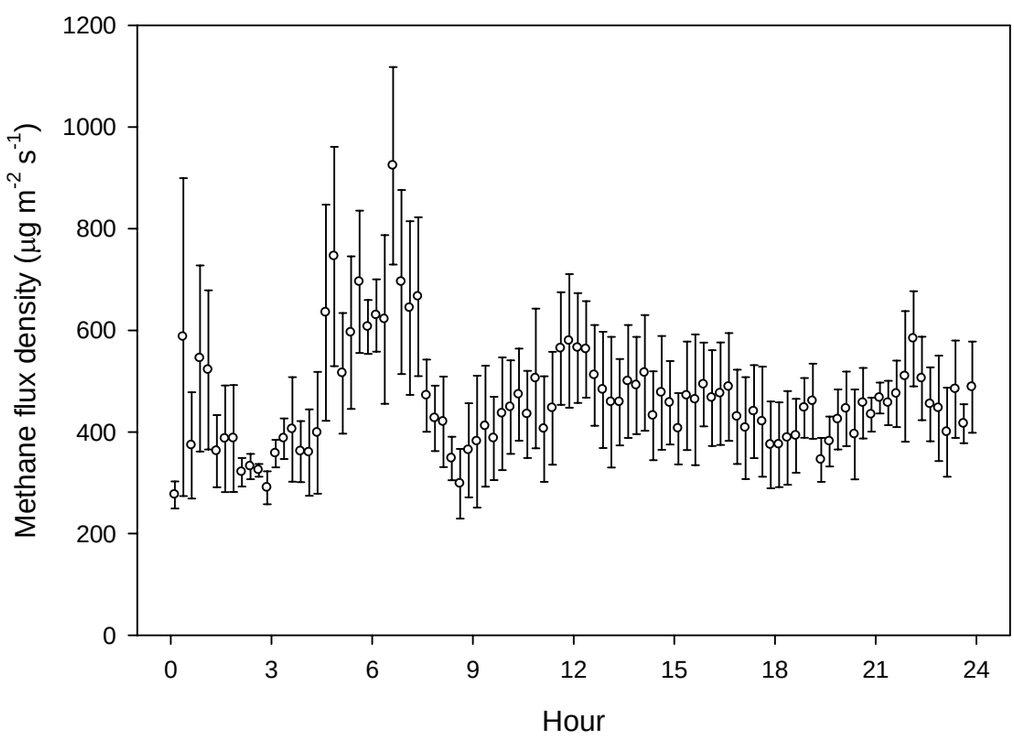

Figure 5. Composite diel methane flux density from lagoons. Error bars are the standard error for each 15-min mean.

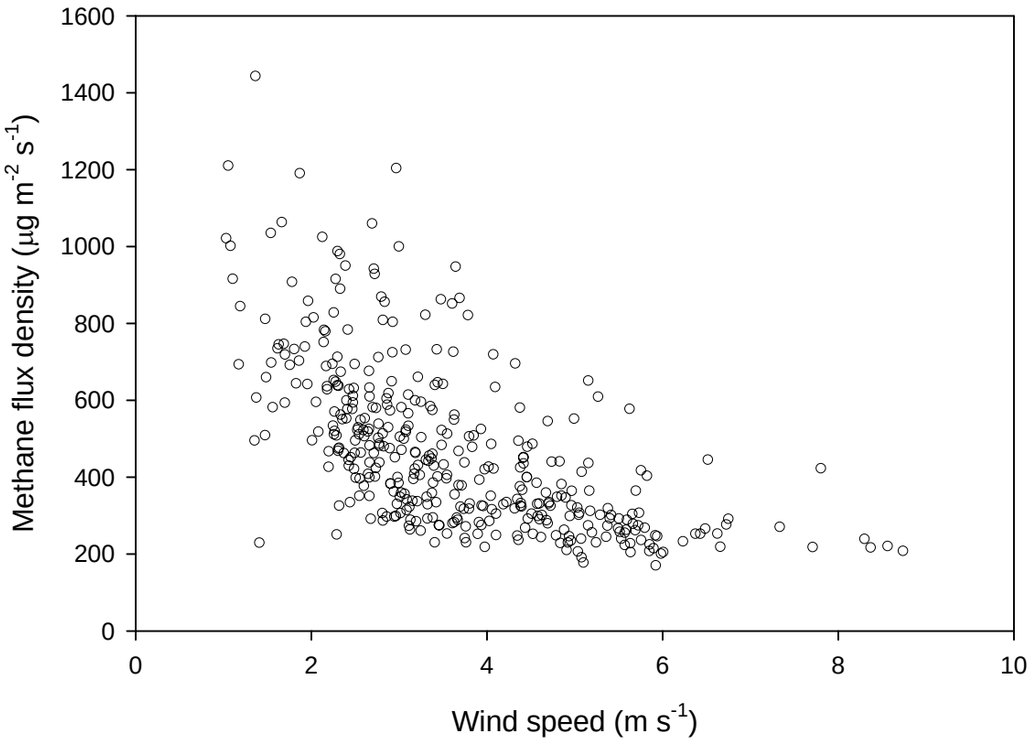

Figure 6. Relationship between wind speed and methane flux density at the lagoon system.