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Methane flux from Mississippi River deltaic plain wetlands

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Abstract. Methane emissions from three wetland habitats in the Mississippi River deltaic plain were measured over a three year period. Flux data collected indicate that each habitat was a net source of methane to the atmosphere throughout the year. Average emission from a *Taxodium distichum* / *Nyssa aquatica* (bald cypress / water tupelo) swamp forest was 146 ± 199 mg CH_4 $m^{-2}d^{-1}$ while emissions from a *Sagittaria lancifolia* (bulltongue) freshwater marsh averaged 251 ± 188 mg CH_4 $m^{-2}d^{-1}$. Methane flux from a *Spartina patens* / *Sagittaria lancifolia* intermediate marsh was significantly higher, 912 ± 923 mg CH_4 $m^{-2}d^{-1}$. Seasonal variation was significant with emissions being higher in the late summer and early fall. Significant diurnal emissions were observed from the *Sagittaria lancifolia* marsh site. Soil temperature (5 and 10 cm depths) was found to be significantly correlated with methane emission from the three sites.

Introduction

The concern over possible climatic change due to the increase in atmospheric concentrations of radiatively active trace gases has been growing over the past quarter century. Methane is of particular interest due to its efficiency in absorption of infrared radiation and important influence on atmospheric chemistry (Cicerone & Oremland l988; Bouwman 1990, 1991). Research efforts have shown that atmospheric methane was increasing approximately 0.8 to 1.1% annually (Steele et al. 1987; Khalil & Rasmussen 1987; Blake & Rowland 1988) but for the past decade methane emissions have steadily decreased (Dlugokencky et al. 1994).

Natural wetlands are estimated to contribute up to 21% of total global emissions (Cicerone & Oremland 1988; Bartlett & Harriss 1993). However, methane emissions within individual wetland regimes are highly variable, both temporally and spatially, due primarily to the heterogeneity of important environmental variables. While temperate wetlands are not major global contributors because of limited area they are good for detailed and mechanistic

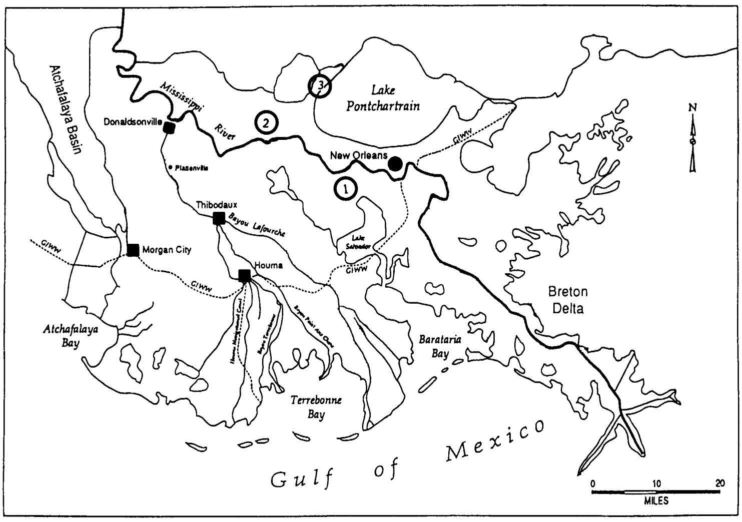

Figure 1. Vicinity map of marsh sites: (1) *Sagittaria lancifolia* freshwater marsh (2) *Taxodium distichum* / *Nyssa aquatic* swamp forest and (3) *Sagittaria lancifolia* / *Spartina patens* intermediate marsh.

field experiments (Bartlett & Harriss 1993). Therefore, long-term field studies are important to discern seasonal and annual methane emissions patterns.

While there has been rather extensive investigation of methane flux from temperate wetlands, few examine the long-term emission patterns. Data compiled by Bartlett & Harriss (1993) demonstrated the presence of both emission and consumption where rates ranged from –8 to 3563 mg CH_4 $m^{-2}d^{-1}$, a difference of greater than three orders of magnitude. DeLaune et al. (1990) estimated emissions from the coastal wetlands of the northern Gulf of Mexico to be 1.5×10^{12} g CH_4-C yr^{-1}.

In this paper, the methane flux data collected over a three year period in three distinct wetland habitats in Louisiana's Mississippi River deltaic plain are presented. This investigation quantifies the diurnal, seasonal and annual methane flux in a forested freshwater swamp, a freshwater marsh and an intermediate marsh habitat. Environmental parameters are examined in relation to observed seasonal emission patterns.

Materials and methods

Site description

Seasonal field methane measurements were determined at three wetland sites in the Mississippi River deltaic plain region of Louisiana (Figure 1). Site

Table 1. Selected properties of the soils investigated. Values given are the means (CV) of three measurements (Crozier et al. 1995).

Soil	Depth (cm)	Bulk Density ($g\ cm^{-3}$)	Organic Matter (%)	Sum. Oxidants[a] ($meq\ kg^{-1}$)	Labile C ($meq\ kg^{-1}$)	ERC[b]
Allemands (freshwater marsh)	0–10	0.07 (16)	70 (11)	92 (22)	1316 (44)	1223 (48)
	10–20	0.08 (34)	62 (20)	223 (21)	266 (74)	43 (561)
	20–30	0.25 (44)	27 (37)	319 (120)	12 (173)	–307 (128)
Barbary (swamp forest)	0–10	0.31 (81)	37 (22)	115 (23)	364 (23)	250 (45)
	10–20	0.22 (14)	34 (12)	102 (9)	368 (33)	266 (42)
	20–30	0.12 (21)	60 (7)	86 (39)	365 (19)	279 (18)
Maurepas (intermediate marsh)	0–10	0.04 (46)	92 (1)	57 (24)	1921 (11)	1863 (11)
	10–20	0.05 (25)	82 (10)	754 (84)	439 (45)	–315 (255)
	20–30	0.09	74	422 (102)	387 (16)	–55 (910)

a = The sum of the equivalents of NO_3^-, SO_4^{2-} and potentially reducible Fe and Mn
b = Excess Reductant Capacity, the difference between equivalents of labile C and the sum of oxidants.

selection was based on differences in soil type and vegetation. The soils at the selected sites were: 1) Allemands muck (clayey, montmorillonitic, euic, thermic Terric Medisparist); 2) Barbary muck (very-fine, montimorillonitic, non-acid, thermic Typic Hydraquent); and 3) Maurepas muck (euic, thermic, Typic Medisparist). The Allemands muck was located in a *Sagittaria lancifolia* marsh in St. Charles Parish, near the town of Boutte. The Barbary muck was located in a *Taxodium distichum* / *Nyssa aquatica* (Cypress / Tupelo) swamp in St. James Parish, near the town of Gramercy. This site was forested with sparse floor vegetation when compared to the other 2 habitats. The Maurepas muck was located in a *Sagittaria lancifolia* / *Spartina patens* intermediate marsh in St. John the Baptist Parish, within the Manchac Wildlife Management area between Lakes Maurepas and Pontchartrain. This intermediate marsh was heavily vegetated with marsh grasses and the soil was highly organic. A list of selected soil properties for each site are provided in Table 1.

Field emissions

The emission measurements at each site were conducted using plexiglass collection chambers described by Lindau et al. (1991). Walkways were constructed near the chambers to minimize sediment disturbance during gas collection periods. Collection chambers consisted of base units ($30 \times 30 \times 30$ cm) permanently installed at each site and clear removable tops ($30 \times 30 \times 30$ cm) which could be sealed to the bases, with floodwater, during methane collections. A sampling port (rubber septum), battery-operated fan, pressure control and thermometer were installed in the chamber tops. The pressure control consisted of 7.6 m of plastic tubing (1.5 mm i.d.) which maintained equilibrium gas pressure between the outside and inside of the chambers. At each gas collection, chamber tops and bases were sealed to determine the linear rate of methane increase in the chambers headspaces. Headspace gas samples were withdrawn through the rubber septum with a gas-tight syringe and transferred into evacuated glass Vacutainers (100 mm length by 16 mm i.d.). A slight over-pressure of collected headspace gas was injected into each Vacutainer to prevent atmospheric contamination (Lindau et al. 1991). Samples collected from the chambers were analyzed for methane using a Shimadzu 14-A flame ionization gas chromatograph fitted with a stainless steel column (0.003 m $\times$ 2.4 m) packed with HayeSep D polymer (100/200 mesh). Column and injector port temperatures were set at 40 and 100 °C, respectively. All gas samples were analyzed within 4 hours of field collection. A closed chamber equation was used to estimate methane fluxes from the soil to the atmosphere (Rolston 1986).

Two diurnal studies were conducted at the Boutte site where emission measurements were made every 4 hours for 24 hours. Diurnal measurements were made on July 28–29 and November 19–20, 1992.

The collected field emission data were analyzed using the multiple regression and analysis of variance procedures in the Statistical Analysis System (SAS 1988). A Duncan multiple range (α = 0.05) test was performed to differentiate class variables.

Results and discussion

Field emissions

Annual methane emissions are summarized in Table 2. The average emissions from the freshwater marsh and forest swamp sites were similar to emission measurements reported for other temperate freshwater environments. Bartlett & Harriss (1993) reported fluxes of approximately 60 to 590 mg CH_4 $m^{-2}d^{-1}$ from Louisiana, Florida and Georgia wetlands. Fluxes from the intermediate marsh site, however, were high in comparison. This may have been due to the predisposition of this site to sporadic or episodic ebullitive releases of methane. Episodic flux has been noted in environments ranging from

Table 2. Methane flux from southeast Louisiana wetland habitats.

Habitat/Location	Avg. CH_4 Flux ($mg\ CH_4\ m^{-2}d^{-1}$)	Number of Observations	Range ($mg\ CH_4\ m^{-2}d^{-1}$) Min	Max
Freshwater marsh – *S. lancifolia*/ Boutte, LA	*251 ± 188	34	48	905
Forested swamp – *T. distichium*/ *N. aquatica*/Gramercy, LA	146 ± 199	40	BD	592
Intermediate marsh – *S. patens*/ *S. lancifolia*/Manchac, LA	912 ± 923	34	13	3910

BD = Below Detection Limit (<3 mg $CH_4\ m^{-2}d^{-1}$)
*See Figure 2 for monthly and seasonal flux rates.

the floodplains of the Amazon Basin (Bartlett et al. 1988) to subartic fens in Canada (Windsor et al. 1992). At no time was methane consumption measured even when floodwater levels were below the soil surface. This is probably due to the fact that even when no standing water was present the organic rich soils remained saturated and reduced.

a. Temporal variability

Several studies have demonstrated the temporal variability of methane flux from natural wetlands. Trends in emissions have been observed diurnally, seasonally and annually (Wilson et al. 1989; Pulliam & Meyer 1992). Seasonal variations have been suggested to be correlated with temperature as well as inundation patterns. Methane emission peaks coincided with the quantity, quality and availability of organic substrates (Pulliman & Meyer 1992). Seasonal variations and temperature effects were observed at each of the three sites in this study. The radar graphs in Figure 2 depict the seasonal methane fluctuations at each site averaged over the three-year period.

In spite of the high variability indicated by the large standard error of the means, it was apparent that annual differences existed between the habitats. Statistical analysis utilizing Duncans Multiple Range test (α = 0.05) has shown that methane emissions from years 1993 and 1994 were not statistically different, but emissions from 1992 were significantly higher. Methane fluxes were lowest and least variable during the winter and early spring months for each year, with no values greater than 200 mg $m^{-2}d^{-1}$ except for the intermediate marsh site (170–1570 mg $CH_4\ m^{-2}d^{-1}$). Highest fluxes were observed in the summer and early fall and fluxes from the freshwater marsh and swamp forest sites varied from 100 to 490 mg $CH_4\ m^{-2}d^{-1}$ compared to a range of 80 to 3400 mg $CH_4\ m^{-2}d^{-1}$ measured from the intermediate marsh.

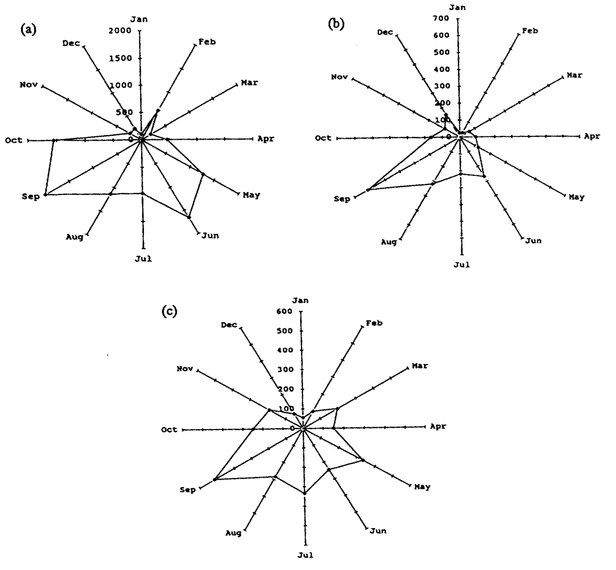

Figure 2. Radar graph of average seasonal variation of methane emissions from a (a) *Spartina patens* / *Sagittaria lancifolia* intermediate marsh (b) *Taxodium distichum* / *Nyssa aquatica* swamp forest (c) *Sagittaria lancifolia* freshwater marsh.

Statistical analysis showed that summer and fall emissions were significantly higher than those measured in winter ($\alpha = 0.05$). Similar results were obtained in a study of a freshwater wetland area in southeast Louisiana (DeLaune et al. 1983).

Environmental parameters did little to explain the annual variability of emissions with the exception of soil temperature. Methane emission was found to be significantly correlated with soil temperature at both 5 cm ($r^2 = 0.25428$; p-value = 0.0241) and 10 cm-depths ($r^2 = 0.21792$; p-value = 0.0082). These findings are consistent with the findings of several other investigations (King & Wiebe 1978, Crill et al. 1988; Wilson et al. 1989; Moore & Knowles 1990). Floodwater levels ($r^2 = 0.14765$; p-value = 0.1291) were not significantly correlated with methane emissions from the three sites. These observations support the findings of Wilson et al. (1989) and Harriss & Sebacher (1981). In an investigation by Sebacher et al. (1986), emissions of methane were positively correlated with water depth up to 10 cm, after which correlation with depth was negative.

The relationship of soil temperature to methane production and emission has been proposed to be a result of temperature effects on microbial metabolism. This effect regulates not only the metabolism of the microorganisms responsible for production and consumption of methane but of the microflora which produce the substrates (King & Wiebe 1978). A study by Wilson et al. (1989) demonstrated the relationship of organic substrate pulses with temperature in regulating methane production. Methane emission maxima were distinguished in the spring, summer, and fall. This investigation suggested that the spring peak emission was the result of labile organic material accumulating over the winter months when low temperatures reduced microbial activity. As temperature increases so did the level of microbial activity, which increased decomposition and the supply of substrate for methanogens. In addition, physiological activity of wetland vegetation was greatly increased in the spring resulting in the release of readily fermented exudates and lysates from rhizospheric systems (Wilson et al. 1989). The summer peak appeared to coincide with the physiological activity of plants where the release of organic material by root systems was increased. Autumn maxima were attributed to the dramatic influx of leaf litter to the system which was readily converted to organic substrate for methane producing bacteria (Whiting & Chanton 1992, 1993).

Diurnal methane flux measurements from the *Sagittaria lancifolia* freshwater marsh site are graphed in Figure 3. During the July 28 and 29 sampling, measurements were highly variable and ranged from <3 mg CH_4 $m^{-2}d^{-1}$ recorded at 2:00 am to a high of approximately 500–525 mg CH_4 $m^{-2}d^{-1}$ measured at the two 10:00 am sampling periods. Diurnal measurements on November 19 and 20 were much lower (seasonal effect) and never exceeded 155 mg CH_4 $m^{-2}d^{-1}$, which was recorded for the 6:30 a.m. sampling time (Figure 3). For both the July and November sampling dates, the lowest methane emissions were measured at 2:00–2:30 a.m.

The results observed during the diurnal studies appear to indicate a plant mediated effect. The role of vegetation as gas conduits has previously been documented in several rice field studies as well as natural wetlands. Chanton et al. (1993) described similar results where pronounced diurnal variation was observed in *T. domingensis* and *T. lancifolia* stands in the Florida Everglades. However, the gas transport process in these plants was dominated by pressurized bulk flow ventilation which was driven by solar illumination. The dominant vegetation at the site of our diurnal study, *S. lancifolia*, has been reported to transport gases independent of solar illumination and stomatal aperture (Sebacher et al. 1985; Harden & Chanton 1994).

b. Spatial variability

Statistical analysis utilizing Duncans Multiple Range test showed that methane flux from the freshwater marsh and swamp forest sites were not significantly different (α = 0.05). For the freshwater marsh site, the medium flux value was 197 mg CH_4 $m^{-2}d^{-1}$ while the mean was 253 mg CH_4 $m^{-2}d^{-1}$. Values

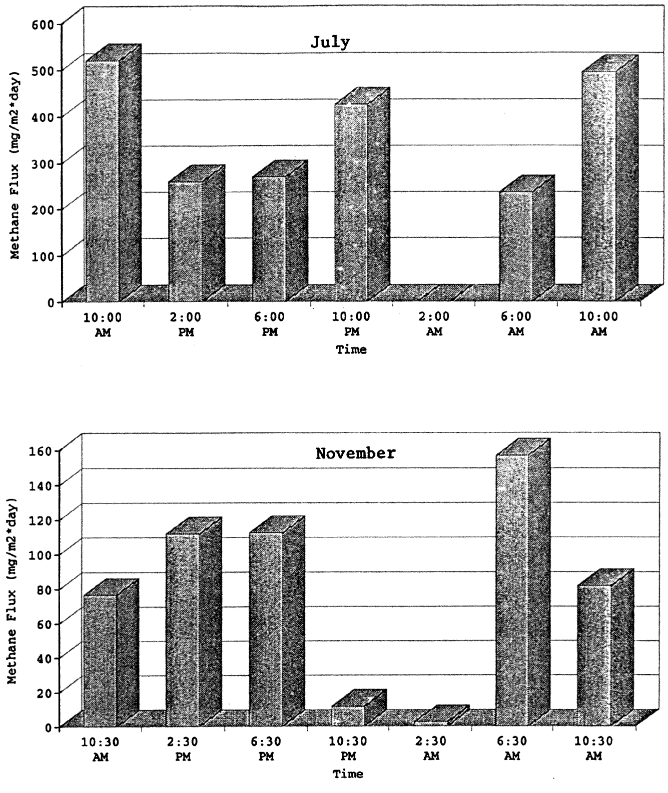

Figure 3. Diurnal variations in methane flux measured at the *Sagittaria lancifolia* freshwater marsh.

for the swamp forest site were 152 and 83 mg CH_4 $m^{-2}d^{-1}$, respectively. Fluxes from the intermediate marsh site were significantly higher compared to the other two sites. The mean and median values were 912 and 582 mg CH_4 $m^{-2}d^{-1}$, respectively.

A possible explanation in the differences in methane emissions from the wetland habitats was the difference in soil properties (see Table 1). Sass et al. (1994) had previously reported the effects of selected soil properties on methane emissions from rice fields. The intermediate marsh soil contained significantly higher amounts of organic matter throughout the profile. In fact, 92% of the first 10 cm of this soil was organic matter. The Barbary soil, of the swamp forest site, was predominantly a mineral soil with 37% of the first 10 cm organic matter. This site consistently demonstrated the lowest methane flux rates of the three habitats. Crozier et al. (1995a) found that the amount of organic matter and labile C positively correlated with the net potential methane production rate.

Crozier et al. (1995b) investigated the possibility of predicting net potential production rates of methane in wetland soils by quantifying the concentrations of redox species and excess soil reductant capacity (ERC). This laboratory study indicated that methane production was positively correlated with ERC which is corroborated by the results of our field study. The Maurepas soil, highest ERC, demonstrated the greatest methane production and emission while methane production in the Barbary soil was significantly less (lower ERC).

Our study demonstrated that soil bulk density may have affected methane emissions. The Barbary soil had the highest bulk density and lowest methane flux relative to the Allemands and Maurepas soils. The lowest bulk density soil (Maurepas) displayed the highest emission rate (Tables 1 and 2).

Methane emissions were higher in late summer and early fall, correlating with temperature in the soil profile. Methane emissions to the atmosphere from Louisiana freshwater wetland varied considerably depending on marsh habitat. Such range in methane emissions should be considered when estimating contributions of freshwater wetland to the global methane budget.

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