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# Gas transfer velocities of $CO_2$ and $CH_4$ in a tropical reservoir and its river downstream

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**Abstract**

We have measured simultaneously the methane ($CH_4$) and carbon dioxide ($CO_2$) surface concentrations and water–air fluxes by floating chambers (FC) in the Petit-Saut Reservoir (French Guiana) and its tidal river (Sinnamary River) downstream of the dam, during the two field experiments in wet (May 2003) and dry season (December 2003). The eddy covariance (EC) technique was also used for $CO_2$ fluxes on the lake. The comparison of fluxes obtained by FC and EC showed little discrepancies mainly due to differences in measurements durations which resulted in different average wind speeds. When comparing the gas transfer velocity ($k_{600}$) for a given wind speed, both methods gave similar results. On the lake and excluding rainy events, we obtained an exponential relationship between $k_{600}$ and $U_{10}$, with a significant intercept at 1.7 cm h$^{-1}$, probably due to thermal effects. Gas transfer velocity was also positively related to rainfall rates reaching 26.5 cm h$^{-1}$ for a rainfall rate of 36 mm h$^{-1}$. During a 24-h experiment in dry season, rainfall accounted for as much as 25% of the $k_{600}$. In the river downstream of the dam, $k_{600}$ values were 3 to 4 times higher than on the lake, and followed a linear relationship with $U_{10}$.


*Keywords:* Tropical environment; Lake; River; Gas exchange; Wind speed; Rainfall

## 1. Introduction

In the context of global warming, the quantification of greenhouse gases emissions from the Earth surface is recognized as a priority. Recently, artificial reservoirs, particularly in the tropics, have been identified as significant $CO_2$ and $CH_4$ contributors to the atmosphere (Galy-Lacaux et al., 1999; Saint Louis et al., 2000; Abril et al., 2005). Owing to the microbial decomposition of soil and flooded biomass composed of primary tropical forest, tropical reservoirs emit large amounts of $CO_2$ and $CH_4$ to the atmosphere (Galy-Lacaux et al., 1999; Abril et al., 2005). A large fraction of the gaseous emissions occurs as diffusive fluxes from the surface of the artificial lakes or from the rivers downstream of the dam (Abril et al., 2005).

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Diffusive $CO_2$ and $CH_4$ fluxes depend on the concentration gradient between the surface water and the atmosphere, which is mainly controlled by the gas concentration in the surface water, and by the gas transfer velocity, $k$. The diffusive $CO_2$ and $CH_4$ fluxes can either be measured directly or calculated from the surface water and air concentrations if $k$ is known. Direct $CO_2$ and $CH_4$ fluxes measurements include three different techniques: the floating chambers (Frankignoulle et al., 1996a), the eddy correlation (McGillis et al., 2001) and the gradient flux techniques (Zappa et al., 2003). Indirect methods consist in measuring the gas concentration air–water gradient and determining $k$ using deliberate tracers such as $SF_6$ (Wanninkhof et al., 1985) or $SF_6/^3He$ (Clark et al., 1994). In addition, measurements must be performed at a frequency that adequately reflects the temporal variations in the gas concentrations in surface waters and fluxes at inter-annual, seasonal and daily time scales. Recently, equilibrator techniques have been developed in order to measure continuously $CO_2$ and $CH_4$ concentrations in systems with rapid temporal variations like estuaries (Frankignoulle et al., 2001) and stratified tropical lakes (Abril et al., 2006). This allows continuous monitoring of gas concentrations variations in surface waters. When combined to an adequate parameterization of $k$, this would allow the calculation of accurate gas emission budgets.

In the present paper, we investigate the dependence of $k$ on various meteorological parameters (wind speed, rainfall, and temperature) in an Amazonian tropical reservoir and its river downstream. We compare gas transfer velocities obtained by floating chamber and eddy covariance measurements of $CO_2$ and $CH_4$ fluxes performed at the same time on the same system. We establish experimental relationships of the gas transfer velocity against wind speed and rainfall and compared them with other studied lakes and rivers.

## 2. Materials and methods

### 2.1. Study site

The Petit-Saut dam was constructed on the Sinnamary River in the tropical forest of French Guiana 100 km upstream its mouth to the Atlantic Ocean. Relevant physical characteristics of the system are shown in Table 1. The reservoir started to be filled in January 1994 and covers 80 km of the Sinnamary River course. At its maximal level of 35 m (first reached in July 1995), 365 km$^2$ of un-cleared tropical forest are flooded. Owing to the differences between high and low water levels, the average surface of the reservoir is 300 km$^2$ (Table 1). Average residence time of waters is 5–6 months. The reservoir water body remains stratified throughout the year with a permanent thermocline around 6–8 m depth. Downstream of the dam, the Sinnamary River has an average depth of 4 m and is influenced by the tide with average amplitude of 0.5 m (Table 1).

### 2.2. Field experiments

Two field experiments were carried out in the reservoir in May and December 2003 during the wet and dry seasons. Intensive measurements of diffusive $CO_2$ ($n$=211) and $CH_4$ ($n$=89) fluxes were performed with floating chambers from a small boat at different sites on the reservoir, including open waters and flooded forest, and on the Sinnamary River and Estuary downstream of the dam. At each station, wind speed and air

Table 1
Characteristics of the Petit-Saut Reservoir

| | | Mean | Range |
|---|---|---|---|
| Meteorology | Wind speed (m s$^{-1}$)[a] | 1.02 | 0–11.50 |
| | Air relative humidity (%)[b] | 86.76 | 38–107 |
| | Annual precipitation (mm)[c] | 2965 | 2156–4538 |
| | Air temperature (°C)[b] | 25.65 | 19.00–36.00 |
| Lake | Surface (km$^2$) | 300 | 260–365 |
| | Volume (10$^9$ m$^3$) | 2.9 | 2.3–3.5 |
| | Water discharge (m$^3$.s$^{-1}$)[d] | 235 | 3–2431 |
| | Turbined water discharge (m$^3$ s$^{-1}$) | 225 | 35–1957 |
| | Depth (m) | 10 | 0–35 |
| | Surface water temperature (°C)[e] | 30.42 | 27.50–33.70 |
| | Thermocline depth (m) | 7.5 | 7–8 |
| Downstream river and estuary | Surface (km$^2$) <40 km | 5 | n.a. |
| | Surface (km$^2$) >40 km | 17 | n.a. |
| | Tidal range (m) | 0.5 | n.a. |
| | Depth | 4 | 3–5 |
| | Water temperature (°C)[f] | 26.8 | 24.8–28.4 |

[a] Monthly average from August 2003 to June 2005.
[b] Monthly average from December 2002 to June 2005.
[c] Annual average from January 1991 to June 2005.
[d] Daily average of the water discharge entering the reservoir from June 1994 to June 2005.
[e] Monthly to bi-monthly average of measurements made at Roche Génipa (reference station since impoundment) from July 1995 to June 2005.
[f] Daily average at 40 km downstream the dam from July 1995 to June 2005.