Methane and carbon dioxide emissions from tropical reservoirs: Significance of downstream rivers

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[1] Methane (CH_4) and carbon dioxide (CO_2) concentrations and water-air fluxes were measured in three tropical reservoirs and their respective rivers downstream of the dams. From reservoirs, CH_4 and CO_2 flux were in the range of 3 ± 2 and 254 ± 392 mmol.m^{-2}.d^{-1}, respectively. Rivers downstream of dams were significantly enriched in CH_4 and CO_2 originating from reservoir hypolimnions. From rivers, CH_4 and CO_2 flux were in the range of 60 ± 38 and 859 ± 400 mmol.m^{-2}.d^{-1}, respectively. Despite their relatively small surfaces, rivers downstream of dams accounted for a significant fraction (9–33% for CH_4 and 7–25% for CO_2) of the emissions across the reservoir surfaces classically taken into account for reservoirs. A significant fraction of CH_4 appeared to degas at the vicinity of the dam (turbines and spillways), although it could not be quantified. **Citation:** Guérin, F., G. Abril, S. Richard, B. Burban, C. Reynouard, P. Seyler, and R. Delmas (2006), Methane and carbon dioxide emissions from tropical reservoirs: Significance of downstream rivers, *Geophys. Res. Lett.*, *33*, L21407, doi:10.1029/2006GL027929.

1. Introduction

[2] In recent years, there has been an increasing concern on greenhouse gas (GHG) emissions from artificial reservoirs, particularly in the tropics, where the flooding of large amounts of carbon from the primary forest, together with high temperatures, lead to high methane (CH_4) and carbon dioxide (CO_2) emissions. *St. Louis et al.* [2000] estimated that CH_4 emissions from reservoirs could represent 12% of global CH_4 emissions, and 90% of this reservoir CH_4 release is suggested to be released from the reservoir in the tropics. At the Petit Saut Reservoir in French Guiana, it was shown that large amounts of CH_4 and CO_2 pass through the turbines and degas downstream of the dam, partly at an aerating weir and partly more downstream in the river [*Abril et al.*, 2005]. At this site, over ten years, about 70% of CH_4 emissions and 40% of CO_2 emissions occurred downstream of the dam. Except for this work at Petit Saut, CH_4 and CO_2 concentrations and emissions have not been measured in rivers downstream of dams and taken into account in the total CH_4 and CO_2 budget of hydroelectric reservoirs. The potential for high GHG emissions by this pathway from Brazilian Reservoirs was pointed out by *Fearnside* [2004] but, without relevant field data, he could not evaluate their importance, which is still under debate [*Fearnside*, 2006; *Rosa et al.*, 2006].

[3] In this paper, we present the first dataset of CH_4 and CO_2 concentrations and fluxes from three South American tropical reservoirs with very different characteristics and that include measurements in the rivers downstream of dams. The Petit Saut Reservoir (French Guiana) is used to describe the seasonal patterns and compared with the Brazilian Balbina and Samuel Reservoirs sampled during the dry season.

2. Sites and Methods

[4] We studied three tropical reservoirs and their respective rivers downstream, located in French Guiana (Petit Saut) and Brazil (Balbina and Samuel). The three reservoirs are very different in terms of age, surface area, residence time of water and depth (Table 1). One particularity of the Petit Saut Reservoir is that an aerating weir was constructed a few hundred meters downstream of the dam in order to re-oxygenate the waters and degas the CH_4 to avoid problems of hypoxia partly due to the intense methanotrophic activity in the river downstream (F. Guérin and G. Abril, manuscript in preparation, 2006). In the two Brasilian reservoirs, the turbined water is evacuated below water, downstream of which turbulence in the water is still very high [*Fearnside*, 2004, 2006]. The three study sites were sampled during the dry season and the Petit Saut reservoir also during the wet season. Sampling in the reservoirs comprised vertical profiles in the water column

Table 1. Relevant Characteristics of the Petit Saut, Balbina and Samuel Reservoirs

Reservoir	Petit Saut	Balbina	Samuel
Country	France	Brazil	Brazil
State	French Guiana	Amazonas	Rondônia
Latitude	05°04′N	01°55′S	08°44′S
Longitude	53°03′W	59°28′W	63°30′W
Average air temperature, °C	25.7	28.8	27.3
Annual precipitation, mm	2965	2740	2280
Date of impoundment	Jan. 1994	Oct. 1987	Nov. 1988
Watershed	Sinnamary	Uatumã	Jamari
Watershed area, km^2	6900	70600	29700
Water discharge, m^3.s^{-1}	267	577	350
Reservoir surface, km^2	270–365	1560–2360	280–559
Volume, km^3	3.5	17.5	4.5
Residence time, month	5–6	11.7	3.5
Mean depth	10	7.4	5.7
Campaigns	Dry (Dec. 2003 & Mar. 2005) and wet seasons (May 2003 & 2005)	Dry Season (Nov. 2004)	Dry Season (Nov. 2004)
Stations in the reservoir	1–9	6	2
Stations in the river	4–9	4	4

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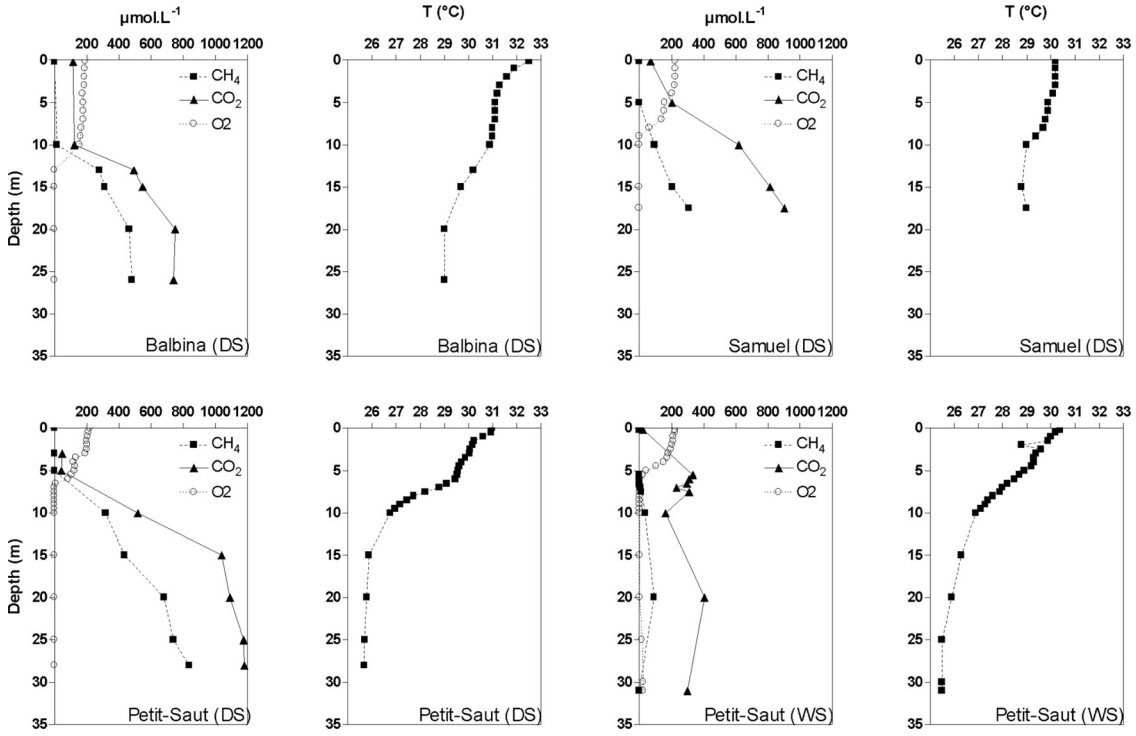

Figure 1. Vertical profiles of temperature (T, °C), O_2, CO_2 and CH_4 concentrations (μmol.L^{-1}) in the water column of the Balbina and Samuel Reservoirs during the dry season (DS) and the Petit Saut Reservoir during the dry and wet seasons (WS).

and surface waters along ~40 km transects in the rivers downstream of dams. Number of surveys and sampling stations in each reservoir and river are detailed in Table 1.

[5] Temperature and O_2 concentration were measured with an HYDROLAB multiprobe system. For oxygen, the polarographic electrode was calibrated at 100% saturation in water-saturated air. Water for CH_4 and CO_2 concentrations was sampled with a peristaltic pump from each sampling depth into replicate serum bottles (30 mL) that were sealed and poisoned with $HgCl_2$ until analysis. CH_4 and CO_2 concentrations were measured one week after sampling after creating a N_2 headspace, and using a gas chromatograph (GC) equipped with a flame ionization detector (FID) and with a thermal conductivity detector (TCD), respectively [*Abril et al.*, 2005; *Guérin et al.*, 2006]. Repeatability on duplicates was better than 5%.

[6] CH_4 fluxes across the water-air interface were measured directly with a floating chamber, from a small boat that was left drifting during measurements. The floating chamber was equipped with a rubber stopper that allowed sampling of the chamber headspace with a syringe and a needle as detailed by *Guérin et al.* [2006]. Gas samples were analyzed with a GC-FID. The gas transfer velocity (k_{600}) was calculated for each sampling site from the concentration and the flux of CH_4 and were then used to determine the CO_2 fluxes from the CO_2 surface concentrations [*Guérin et al.*, 2006, and references therein].

3. Results

3.1. Concentrations and Fluxes of CH_4 and CO_2 in the Reservoirs

[7] Figure 1 shows representative vertical profiles of temperature and O_2, CO_2 and CH_4 concentrations in the water column of the three reservoirs. More vertical profiles are shown in Table S1 in the auxiliary material[1]. Average concentrations in the epi- and hypolimnions are reported in Table 2. During the dry season, oxycline depths were 11 m, 10 m and 4.5 m respectively in the Balbina, Samuel and Petit Saut reservoirs (Figure 1). At Petit Saut during the wet season, the oxycline depth increased to 8 m. At all sites and seasons, the oxycline depths were very close to the thermocline depths and the hypolimnions were anoxic. CH_4 and CO_2 concentrations increased with depth and showed a maximal gradient at or just below the oxycline, except for CO_2 at Petit Saut during the wet season (Figure 1). During the wet season, CH_4 concentrations in the anoxic hypolimnions reached 800 μmol.L^{-1} at Petit Saut, 440 μmol.L^{-1} at Balbina, and only 220 μmol.L^{-1} at Samuel. CO_2 concentrations reached 1180 μmol.L^{-1} at Petit Saut, 780 μmol.L^{-1} at Balbina, and 880 μmol.L^{-1} at Samuel. Consequently, CH_4:CO_2 ratios in the hypolimnions were significantly lower in the Samuel reservoir (~0.3) than at Balbina and Petit Saut (~0.7). At Petit Saut, from Dec. (dry) to May (wet), gas concentrations decreased in the hypolimnion, from 702 ± 185 to 223 ± 25 μmol.L^{-1} for CH_4 and from 1369 ± 292 to 669 ± 415 μmol.L^{-1} for CO_2 (Table 2 and Figure 1).

[8] During the dry season, CH_4 fluxes from the reservoirs surfaces in mmol.m^{-2}.d^{-1} were 2 ± 3 at Balbina, 0.7 ± 0.5 to 2.7 ± 1.6 at Petit Saut and 5 ± 6 at Samuel. Respective CO_2 fluxes were 76 ± 46 mmol.m^{-2}.d^{-1} at Balbina, 103 ± 68 to 131 ± 110 at Petit Saut and 976 ± 1213 at Samuel (Table 3). Higher fluxes at the Samuel Reservoir than at the two other sites (Table 3), beside similar concentrations in the epilimni-

[1]Auxiliary materials are available at ftp://ftp.agu.org/apend/gl/2006gl027929.

Table 2. CH_4 and CO_2 Concentration Measured at the Petit Saut, Samuel and Balbina Reservoirs[a]

			CH_4 (μmol.L^{-1})			CO_2 (μmol.L^{-1})		
Reservoir	Date	Season	Epilimnion[b]	Hypolimnion[c]	Downstream[d]	Epilimnion[b]	Hypolimnion[c]	Downstream[d]
Petit Saut	May 2003	Wet	0.3 ± 0.1 (23)	223 ± 25 (33)	64 (1)	148 ± 58 (7)	669 ± 415 (15)	323 (1)
	Dec. 2003	Dry	10.3 ± 10.9 (22)	702 ± 185 (20)	92 (1)	229 ± 156 (22)	1369 ± 292 (20)	426 (1)
	Mar. 2005	Dry	2.4 ± 2.8 (3)	121 ± 31 (9)	48 (1)	120 ± 12 (3)	571 ± 59 (9)	311 (1)
	May 2005	Wet	0.3 ± 0.1 (3)	34 ± 46 (11)	22 (1)	41 ± 39 (3)	347 ± 106 (11)	206 (1)
Balbina	Nov. 2004	Dry	9.3 ± 10.3 (12)	424 ± 139 (15)	77 ± 7 (3)	119 ± 29 (12)	596 ± 146 (15)	203 ± 27 (3)
Samuel	Nov. 2004	Dry	1.9 ± 0.2 (4)	257 ± 72 (4)	40 (1)	154 ± 59 (4)	778 ± 218 (4)	337 (1)

[a]Average ± SD and number of measurements.
[b]Define as the first 5 m below the water surface at Petit Saut and 10 m at the two other sites.
[c]Define as water below 10 m depth at Petit Saut and 15 m at the two other sites.
[d]Station located a few hundred meters downstream of the dam.

on (Table 2) were due to weather conditions during measurements (high wind speed and rainfall rates). This enhanced the k_{600} (Table 3) as observed at the Petit Saut Reservoir under intense rainfall [*Guérin et al.*, 2006]. At the Petit Saut Reservoir, CO_2 fluxes showed very little seasonal variation, whereas CH_4 fluxes significantly varied from one survey to another, but without consistent seasonal trends (Table 3). CH_4 and CO_2 fluxes measured during these surveys are well within the range previously reported in tropical reservoirs [e.g., *Abril et al.*, 2005; *dos Santos et al.*, 2006], except at Samuel, where CO_2 fluxes (118–1834 mmol.m^{-2}.d^{-1}) were much higher than those of *dos Santos et al.* [2006] at the Samuel Reservoir (142–169 mmol.m^{-2}.d^{-1}) due to exceptional weather conditions during our survey. Further in this paper, we use the CO_2 fluxes of *dos Santos et al.* [2006] as more representative of average conditions.

3.2. CH_4 and CO_2 Concentrations and Fluxes in Downstream Rivers

[9] CH_4 and CO_2 concentrations a few hundred meters downstream of the three dams were high at all sites and seasons, in the ranges of 22 to 92 μmol.L^{-1} for CH_4 and of 203 to 337 μmol.L^{-1} for CO_2 (Table 2 and Figure 2). Downstream of the three dams, CH_4 concentrations decreased along the longitudinal transects in the rivers (Figure 2). This decrease was fast at Samuel, intermediate at Petit Saut and slow at Balbina, where CH_4 remained at 10 μmol.L^{-1} 30 km downstream of the dam (Figure 2). At the Samuel and the Petit Saut Reservoirs, CH_4 concentrations 40 km downstream were lower than 1 μmol.L^{-1}. CO_2 concentrations also showed a decreasing trend downstream in all rivers, except at Petit Saut during the wet seasons (Figure 2). The decreases in CO_2 concentration with distance downstream was however much slower than for CH_4. Downstream of the dams, average CH_4 and CO_2 fluxes were 165 and 7 times higher than fluxes from the reservoir surfaces, respectively (Table 3). These differences were due to higher surface concentrations and k_{600} values in all rivers compared to reservoirs (Table 3). At the Balbina and the Petit Saut Reservoirs during the dry season, CO_2 fluxes in the rivers downstream of the dams were between 400 and 830 mmol.m^{-2}.d^{-1} and CH_4 fluxes were between 60 and 114 mmol.m^{-2}.d^{-1} (Table 3 and Figure 2). The lowest CH_4 fluxes (12 ± 13 mmol.m^{-2}.d^{-1}) and the highest CO_2 fluxes (1494 ± 963 mmol.m^{-2}.d^{-1}) of this study were measured downstream of the Samuel Dam (Table 3 and Figure 2), consistent with the lowest CH_4:CO_2 ratio in the hypolimnion of the Samuel Reservoir (Table 2 and Figure 1).

4. Discussion

4.1. Impact of Reservoirs on CH_4 and CO_2 Fluxes in Rivers

[10] Methane concentrations in rivers are about 100 times higher downstream of dams compared to natural rivers (Table 4). At Petit Saut, CH_4 concentrations in the Sinnamary River were 80 to 200 times higher downstream of the dam than upstream of the reservoir (Table 4). Similar increases in CH_4 concentrations due to damming have been reported in some Pacific Northwest Rivers [*Lilley et al.*, 1996] and on the Tyne River, UK [*Upstill-Goddard et al.*, 2000]. Rivers are indeed ecosystems where oxic conditions generally prevail and where CH_4 production is rather limited. Methane found in rivers is produced in majority in surrounding areas like floodplains [*Richey et al.*, 1988] or soils and groundwaters [*Jones and Mulholland*, 1998]. Along the watercourse of the three studied rivers, there is a dominance of tropical forest over wetlands and natural

Table 3. CH_4 and CO_2 Atmospheric Fluxes ($F(CH_4)$ and $F(CO_2)$) and Gas Transfer Velocity (k_{600}) Measured at the Petit Saut, Samuel and Balbina Reservoirs and in the Rivers Downstream of Dams (Average ± SD and Number of Measurements)[a]

			$F(CH_4)$ mmol.m^{-2}.d^{-1}		$F(CO_2)$ mmol.m^{-2}.d^{-1}		k_{600} cm.h^{-1}	
Reservoir	Date	Season	Reservoir	River	Reservoir	River	Reservoir	River
Petit Saut	May 2003[b]	Wet	7.7 ± 8.8 (18)	45 ± 34 (23)	133 ± 116 (50)	945 ± 340 (35)	3 ± 2 (21)	12 ± 7 (35)
	Dec. 2003[b]	Dry	2.7 ± 1.6 (17)	59 ± 59 (31)	131 ± 110 (117)	829 ± 208 (33)	3 ± 3 (133)	10 ± 6 (41)
	Mar. 2005[c]	Dry	0.1 ± 0.1 (3)	84 ± 38 (7)	103 ± 68 (3)	802 ± 364 (7)	3 ± 2	11 ± 5
	May 2005	Wet	0.7 ± 0.5 (6)	47 ± 27 (4)	102 ± 143 (6)	670 ± 95 (4)	3 ± 2 (6)	11 ± 5 (4)
Balbina	Nov. 2004	Dry	2.1 ± 3.0 (6)	114 ± 66 (5)	76 ± 46 (6)	412 ± 95 (5)	3 ± 2 (6)	8 ± 1 (5)
Samuel	Nov. 2004	Dry	5.0 ± 5.9 (2)	12 ± 13 (4)	976 ± 1213 (2)	1494 ± 963 (4)	22 ± 22 (2)	8 ± 10 (4)

[a]Fluxes and Concentrations of CH_4 were measured on each site and were used to compute k_{600} values which were used to calculate $F(CO_2)$, otherwise specified in footnote.
[b]$F(CO_2)$ determined by floating chambers and by eddy-covariance.
[c]$F(CH_4)$ and $F(CO_2)$ were computed using the k_{600}-wind relations from *Guérin et al.* [2006] and surface concentration.

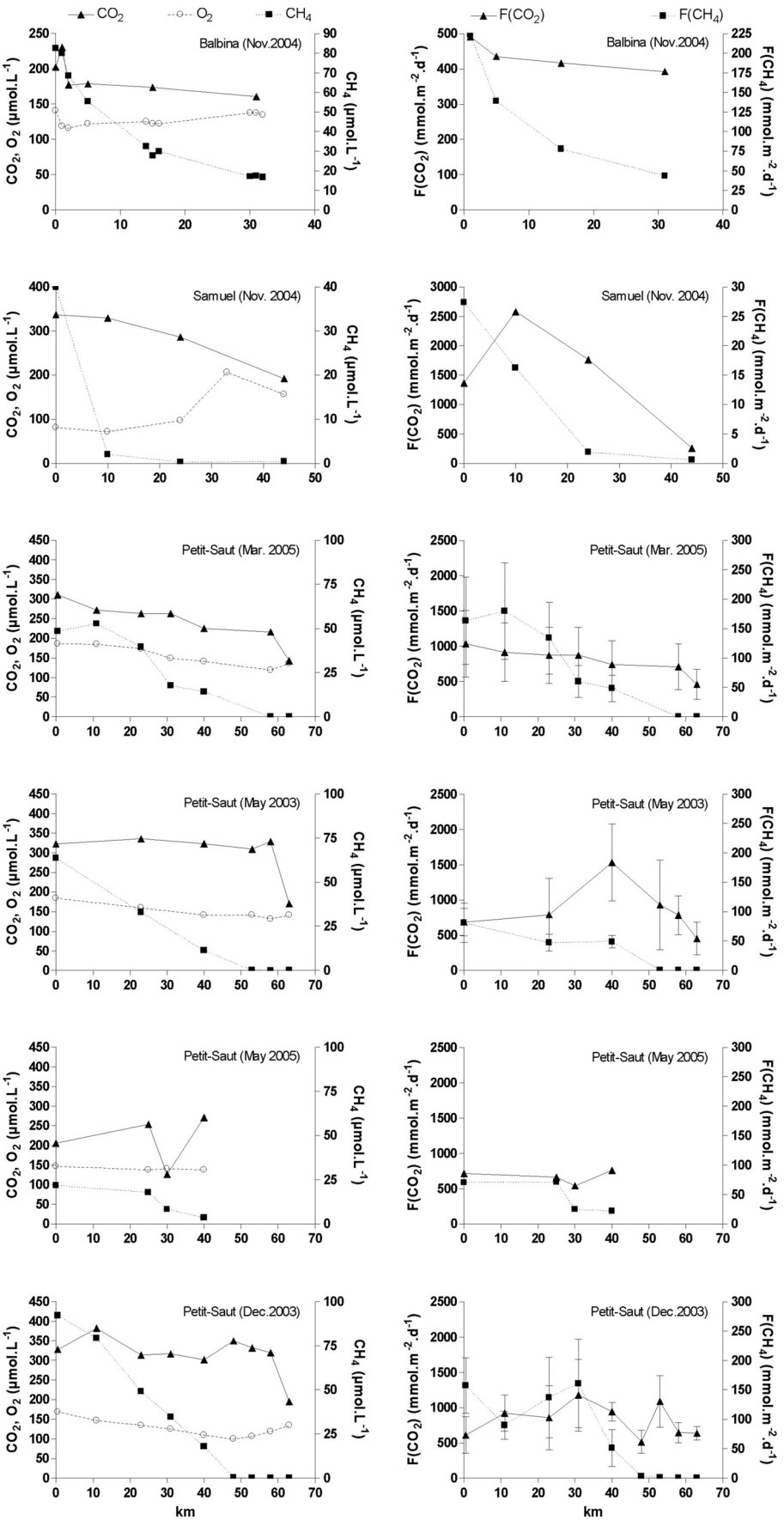

Figure 2. Longitudinal pattern of CO_2, CH_4 and O_2 concentrations (μmol.L^{-1}) and CO_2 and CH_4 fluxes measured in the rivers downstream of the Balbina, Samuel and Petit Saut Reservoirs. Note the different scales in each part.

Table 4. Partial Pressure of CO_2 (pCO_2) and CH_4 (pCH_4) in "Natural" Rivers and in Rivers Downstream of Dams[a]

	River	pCO_2, ppmv	Reference	pCH_4, ppmv[b]	Reference
Natural river	Temperate rivers	676–9574	1	4.35–2465	2
	Amazonian rivers	3000–12000	3	72 ± 131	4
	Sinnamary[c]	2900–6000	5	435–1740	5
Downstream of reservoir	Sinnamary	6500–11000	5	31900–133400	5
	Uatuma	7300	5	111650	5
	Jamari	11000	5	60900	5

[a]Ref.: 1: *Cole and Caraco*, 2001, 2: *Upstill-Goddard et al.*, 2000, 3: *Richey et al.*, 2002, 4: *Richey et al.*, 1988, 5: This study.
[b]CH_4 partial pressure were calculated from concentrations assuming a conversion factor of 1 ppmv for 1.45 nmol.L^{-1} which corresponds to a temperature of 20°C.
[c]Upstream of the Petit Saut Reservoir.

CH_4 sources are probably very limited compared to the reservoirs. Downstream of dams, most of the CH_4 originates from the reservoir hypolimnions, as a result of anaerobic decomposition of the flooded soils and vegetation [*St. Louis et al.*, 2000; *Abril et al.*, 2005].

[11] When considering all individual sites and seasons in Table 2, we found a significant correlation between the CH_4 concentration downstream of the dams and in the hypolimnion ($r^2 = 0.80$). The slope of the relationship was very low (0.1), which suggests that a similar loss occurs in the turbines and spillways at the three sites. At Petit Saut, an aerating weir enhances the CH_4 degassing, which contributed to ~60% of the total flux from the system for the year 2003 [*Abril et al.*, 2005]. Our results support the assumption by *Fearnside* [2004] that some important CH_4 degassing also occurs in the Brazilian dams, which could be 40% of the CH_4 passing through the turbines [*Fearnside*, 2006]. A much more precise investigation, including sampling in the turbines up- and downstream is needed in order to address definitively the question of degassing at the outlet of dams [*Fearnside*, 2006; *Rosa et al.*, 2006]. The decrease of CH_4 concentrations with distance downstream in the three rivers (Figure 2) is due to both degassing and microbial oxidation. At Petit Saut, we have shown that 60% of the CH_4 entering the Sinnamary River downstream of the dam was lost to the atmosphere, the remaining 40% being oxidized aerobically [*Abril et al.*, 2005] (F. Guérin and G. Abril, manuscript in preparation, 2006). This process was also responsible for part of the O_2 decrease (Figure 2) as demonstrated at Petit Saut (F. Guérin and G. Abril, manuscript in preparation, 2006).

[12] Concerning CO_2, the impact of damming seems less pronounced than for CH_4 (Table 4). Indeed, pCO_2 in the dammed rivers are higher than in temperate rivers and peatland streams [*Hope et al.*, 2001], but similar to those reported in Amazonian Rivers [*Richey et al.*, 2002]. Natural rivers are known to show very large CO_2 supersaturations and atmospheric fluxes, due to direct inputs of soil CO_2 and to mineralization of terrestrial organic matter in waters and sediments [*Cole and Caraco*, 2001; *Hope et al.*, 2001; *Richey et al.*, 2002]. In the case of Petit Saut, pCO_2 in the Sinnamary River was more than two times higher downstream of the dam than upstream of the reservoir (Table 4). In addition, for the three reservoirs, CO_2 concentrations in the downstream rivers were correlated with those in the hypolimnion of the reservoirs ($r^2 = 0.7$, slope = 0.2). These two facts reveal that mineralization of flooded soils and vegetation in reservoirs is an additional source of CO_2 for the downstream rivers. By contrast to CH_4, CO_2 concentrations and fluxes remain high and relatively constant for a long distance along the three studied river sections (Figure 2). At Petit Saut, it was shown that the CO_2 entering the river downstream of the turbines and weir accounted for only ~25% of the CO_2 emitted by the 40 km section of the Sinnamary River [*Abril et al.*, 2005]. The additional CO_2 emitted to the atmosphere originates from mineralization of organic matter in the river waters, CH_4 oxidation and lateral CO_2 sources from soils along the watercourse. Part of the labile organic matter respired in the rivers is produced in the reservoir by phytoplankton and from flooded soils and vegetation; another part may originate from the watershed. Intense respiration in the river, together with CH_4 oxidation, both contribute to the low O_2 concentration all along the three river section (Figure 2). The net impact of the dams on the CO_2 degassing in the rivers is however difficult to assess. A more detailed study of organic matter dynamics along the reservoir-river continuum, including a fine characterization of its different sources and behavior, would be required in order to answer this question.

4.2. CH_4 and CO_2 Emissions From Downstream Rivers

[13] Emissions by rivers downstream of dams were usually neglected in the estimations of CO_2 and CH_4 emissions from hydroelectric reservoirs [*St. Louis et al.*, 2000; *dos Santos et al.*, 2006]. Downstream of the three reservoirs, CH_4 emissions by diffusive fluxes including the export term were 16, 0.7 and 3 tC-CH_4.d^{-1} for the Balbina, Samuel and Petit Saut Reservoir, that is similar to the bubbling fluxes from these reservoirs (Table 5) [*Abril et al.*, 2005; *dos Santos et al.*, 2006]. Downstream rivers contributed to 23%, 5% and 9–33% of the total CH_4 emissions across the surfaces (diffusive flux plus bubbling) of the Balbina, Samuel and Petit Saut Reservoirs, respectively (Table 5). CO_2 emissions plus export downstream of the dams ranged from 100 to 160 tC-CO_2.d^{-1} and contributed to about 20% of emissions by diffusive flux from the surfaces of the Samuel and Petit Saut Reservoirs and 7% for the Balbina Reservoir (Table 5). We must note, however, several important facts. First, a fraction of the CH_4 exported (very significant at Balbina) which is oxidized in the river water, will not reach the atmosphere (F. Guérin and G. Abril, manuscript in preparation, 2006). Second, all of the river CO_2 emissions cannot be attributed to the presence of the reservoirs, as rivers naturally emit large quantities of CO_2; Third, degassing in the turbines or immediately downstream of the dam is not taken into account in this budget; at Petit Saut, degassing at the aerating weir was a major pathway for CH_4 but not for CO_2 and accounted for

Table 5. Atmospheric Emissions ($tC.d^{-1}$) of CO_2 and CH_4 From the Balbina, Samuel, and Petit Saut Reservoirs and From the Downstream Rivers, and Export of the Dissolved CO_2 and CH_4 Downstream in River Waters[a]

			Reservoir		River	
	Site	Season	Diffusive	Bubbling[b]	Diffusive[c]	Export[d]
CH_4	Balbina	Dry	40 ± 56	13 ± 3[e]	6 ± 4	10.0 ± 0.2
	Samuel	Dry	17 ± 20[e]	2 ± 1[e]	0.7 ± 0.8	0.2 ± 0.0
	Petit Saut	Dry	5 ± 6	1.0 ± 0.5[f]	3 ± 1	<0.1
		Wet	18 ± 21	1.0 ± 0.5[f]	2 ± 0.1	1.0 ± 1.0
CO_2	Balbina	Dry	1462 ± 864	0	22 ± 6	96 ± 16
	Samuel	Dry	486 ± 86[e]	0	90 ± 58	70 ± 24
	Petit Saut	Dry	398 ± 38	0	40 ± 14	60 ± 20
		Wet	507 ± 95	0	38 ± 10	62 ± 30

[a]Note that degassing at the dam is not included in the budget (see text).
[b]Bubbling occurs only where water depth is lower than 10m, that is half of the surface area for the Petit Saut Reservoir and 2/3 for the two other sites.
[c]Only the first 40 km downstream of the Petit Saut reservoir were considered for comparison with the other sites.
[d]Export of excess CO_2 and CH_4 downward from the last sampling station.
[e]Data from *dos Santos et al.* [2006].
[f]Data from *Abril et al.* [2005].

about 60% of total CH_4 emissions during the 10-year period from filling [*Abril et al.*, 2005]. At the two other reservoirs, the potential degassing at the vicinity of the dam cannot be quantified with our sampling strategy, although *Fearnside* [2006] argued that, at Balbina, 40% of the CH_4 passing through the turbines could be released to the atmosphere. The differences in concentrations in the hypolimnions and in the rivers (Table 2) suggest that degassing could be significant at Samuel and Balbina. Intensive sampling specially dedicated to this question is needed in order to improve GHG budgets from tropical hydroelectric reservoirs. *St. Louis et al.* [2000] have shown that reservoirs constitute a significant CH_4 source in the tropics. Their estimate concerns reservoir surfaces only and should be reassessed by taking into account CH_4 fluxes downstream of dams (degassing + river).

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