Carbon cycling in the epilimnion of Lake Kivu (East Africa): surface net autotrophy and emission of CO_2 to the atmosphere sustained by geogenic inputs

A.V. Borges[1,*], Bouillon S.[2], Morana C.[2], P. Servais[3], J.-P. Descy[4], F. Darchambeau[1]
[1] Université de Liège (BE) [2] KULeuven (BE), [3] Université Libre de Bruxelles (BE), [4] Université de Namur (BE), * alberto.borges@ulg.ac.be

We report organic and inorganic carbon distributions and fluxes in Lake Kivu acquired during four cruises that capture the seasonal variations (March 2007 - mid rainy season, September 2007 - late dry season, June 2008 - early dry season, and April 2009 - late rainy season). The partial pressure of CO_2 (pCO_2) in surface waters of the main basin of Lake Kivu showed modest spatial variations (coefficient of variation between 3% and 6%), and modest seasonal variations with an amplitude of 163 ppm (between 579±23 ppm on average in March 2007 and 742±28 ppm on average in September 2007). The most prominent spatial feature of the pCO_2 distribution was the very high pCO_2 values in Kabuno Bay (a small sub-basin of Lake Kivu) ranging between 13158 ppm and 14213 ppm (between 18 and 26 times higher than in the main basin). Surface waters of the main basin of Lake Kivu were a net source of CO_2 to the atmosphere at an average rate of 5.9 mmol m^{-2} d^{-1} which is lower than the global average reported for freshwater (16.0 mmol m^{-2} d^{-1}), saline (81 to 105 mmol m^{-2} d^{-1}) and volcanic lakes (458 to 51,183 mmol m^{-2} d^{-1}). In Kabuno Bay, the CO_2 emission to the atmosphere was on average 274.8 mmol m^{-2} d^{-1} (~46 times higher than in main basin).

The deepening of the mixed layer and entrainment of deeper waters to the surface mixed layer was main driver of the seasonal variations of CH_4 as shown by the positive correlation of pCO_2 and CH_4, of pCO_2 and the mixed layer depth, and of pCO_2 and $\delta^{13}C_{DIC}$. Indeed, deeper waters have higher pCO_2 and CH_4, and dissolved inorganic carbon (DIC) is more ^{13}C-depleted than that in surface waters.

In order to test if vertical mixing was the only driver of seasonal variations of pCO_2, we computed DIC whole-lake mass balance of bulk concentrations and of stable isotopes. The budgets show that the input of DIC from depth and export by the Ruzizi (the only outflow of the lake) were the main players in the DIC budget. Export of $CaCO_3$ was significant. There was a net loss of carbon from surface waters that can only ascribed to export of POC to depth, hence, we show that the epilimnion of Lake Kivu was net autotrophic. This is due to the modest river inputs of organic carbon owing to the small ratio of catchment area to lake surface area (2.15), and implies that the CO_2 emission to the atmosphere must be sustained by DIC inputs from depth of geogenic origin from deep geothermal springs.

Based on metabolic rate measurements and mass balance considerations, we show that bacterial respiration is not solely sustained by particulate primary production, and is substantially sustained by dissolved primary production. This leads to moderate to high levels of Percent of extracellular release (PER).

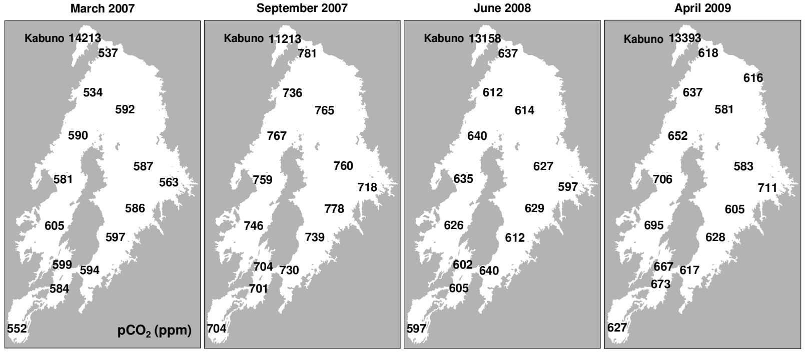

Table : Photic depth (*Ze*), chlorophyll-a concentration (Chl-*a*), particulate net primary production (PNPP), bacterial production integrated over *Ze* (BP), bacterial respiration (BR), and percent of extracellular release (PER, %), at two stations in the main basin of Lake Kivu [Kibuye, Ishungu], in March 2007, September 2007, June 2008, and April 2009

		Ze	Chl-*a*	PNPP	BP	BR	PNPP-BR	PER
		(m)	(mg m^{-3})	(mmol m^{-2} d^{-1})	(mmol m^{-2} d^{-1})	(mmol m^{-2} d^{-1})	(mmol m^{-2} d^{-1})	(%)
March 2007								
15/03/2007	Kibuye	18	38.3	27.0	23.2	35.7	-8.7	54
17/03/2007	Kibuye	20	48.4	42.5	25.8	39.9	2.6	33
23/03/2007	Ishungu	17	36.1	49.7	40.5	49.6	0.1	32
September 2007								
09/09/2007	Kibuye	19	56.4	42.9	35.9	47.9	-5.0	42
12/09/2007	Kibuye	18	55.1	45.9	34.0	45.9	0.1	36
04/09/2007	Ishungu	20	48.2	*n.d.*	16.0	29.9	*n.d.*	*n.d.*
June 2008								
23/06/2008	Kibuye	24	42.8	46.0	7.7	21.6	24.4	3
11/07/2008	Kibuye	20	37.8	42.0	11.1	24.3	17.7	17
03/07/2008	Ishungu	19	28.1	40.7	3.9	13.6	27.1	-4
April 2009								
04/05/2009	Kibuye	21	22.9	14.2	49.8	61.2	-47.0	82
21/04/2009	Ishungu	24	39.3	24.5	43.5	58.9	-34.4	68