BELLA workshop
Brussels, 12 June 2007
http://www.co2.ulg.ac.be/

Carbon dioxide fluxes in lake Kivu

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Atmospheric CO_2 fluxes in lakes

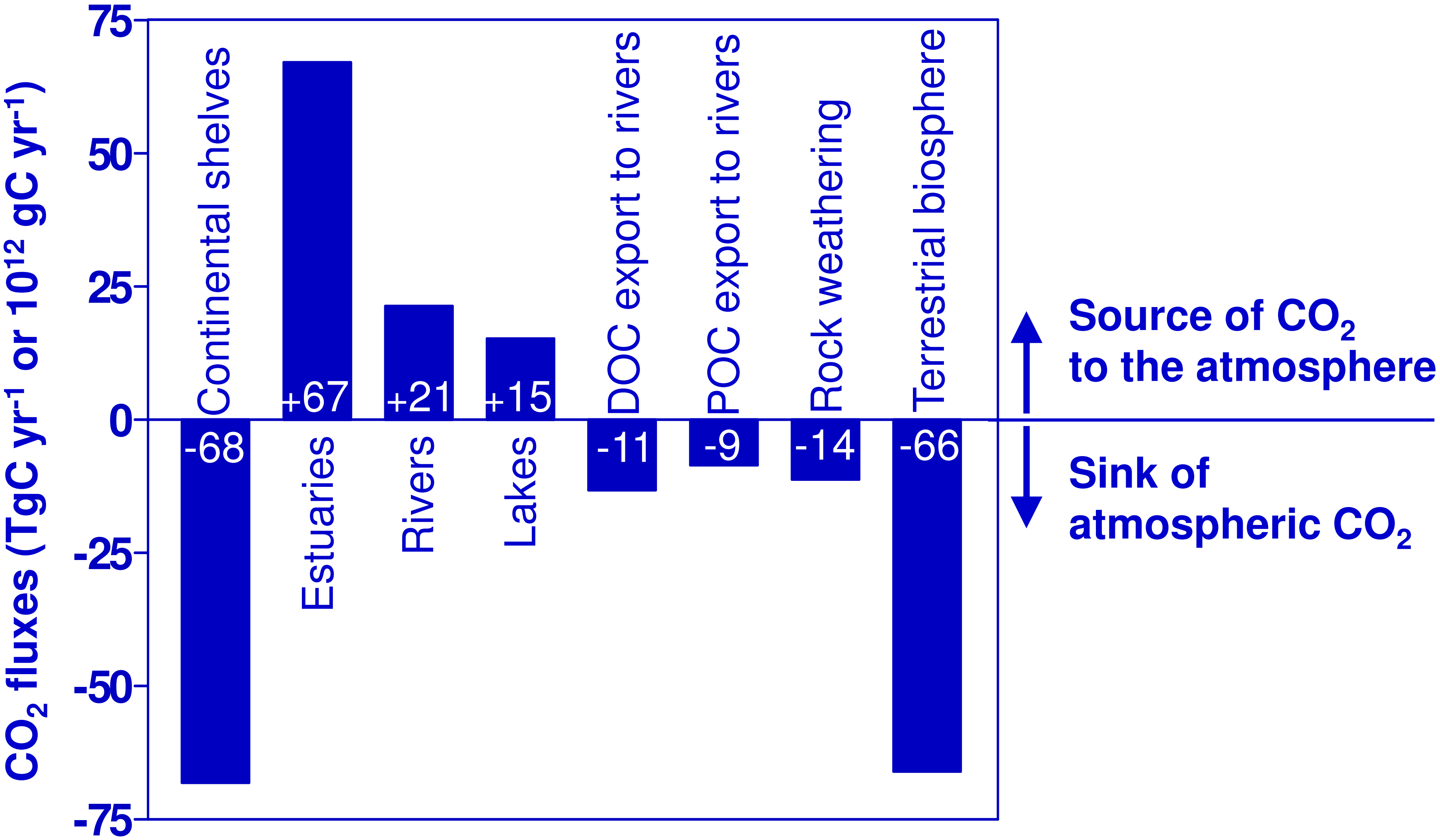
Global air-water CO_2 fluxes in aquatic systems (PgC yr^{-1} or 10^{15} gC yr^{-1})

Oceans	-1.22	Takahashi et al. (2007)
Rivers	+0.30	Cole and Caraco (2001)
Lakes	+0.14	Cole et al. (1994)

Surface oceans / surface lakes = 1470

Atmospheric CO_2 fluxes in lakes

European CO_2 fluxes in aquatic and terrestrial systems (10^{12} gC yr^{-1})



Borges et al. (2006) ECSS 70: 375-387

Atmospheric CO_2 fluxes in lakes

CO_2 emission of lakes driven by net heterotrophy fuelled by terrestrial (allochtonous) organic carbon inputs

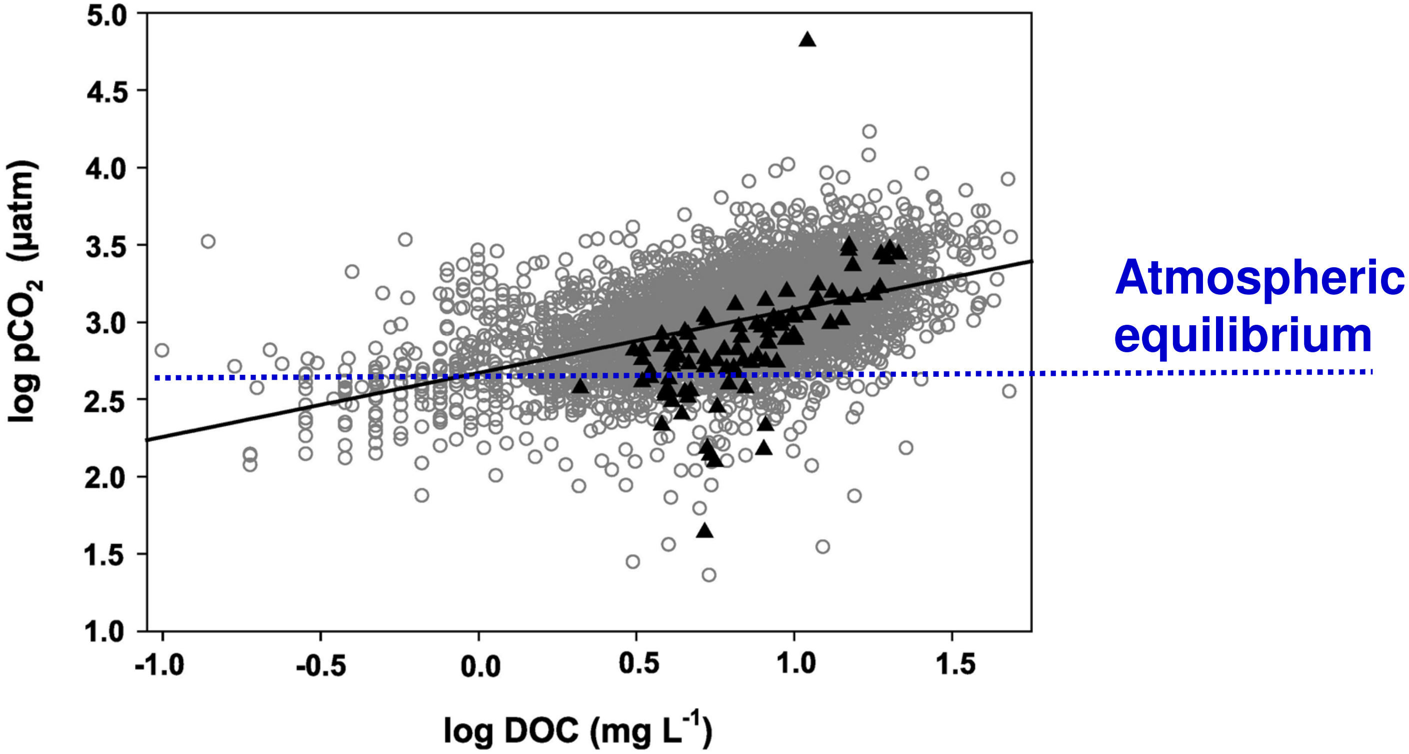
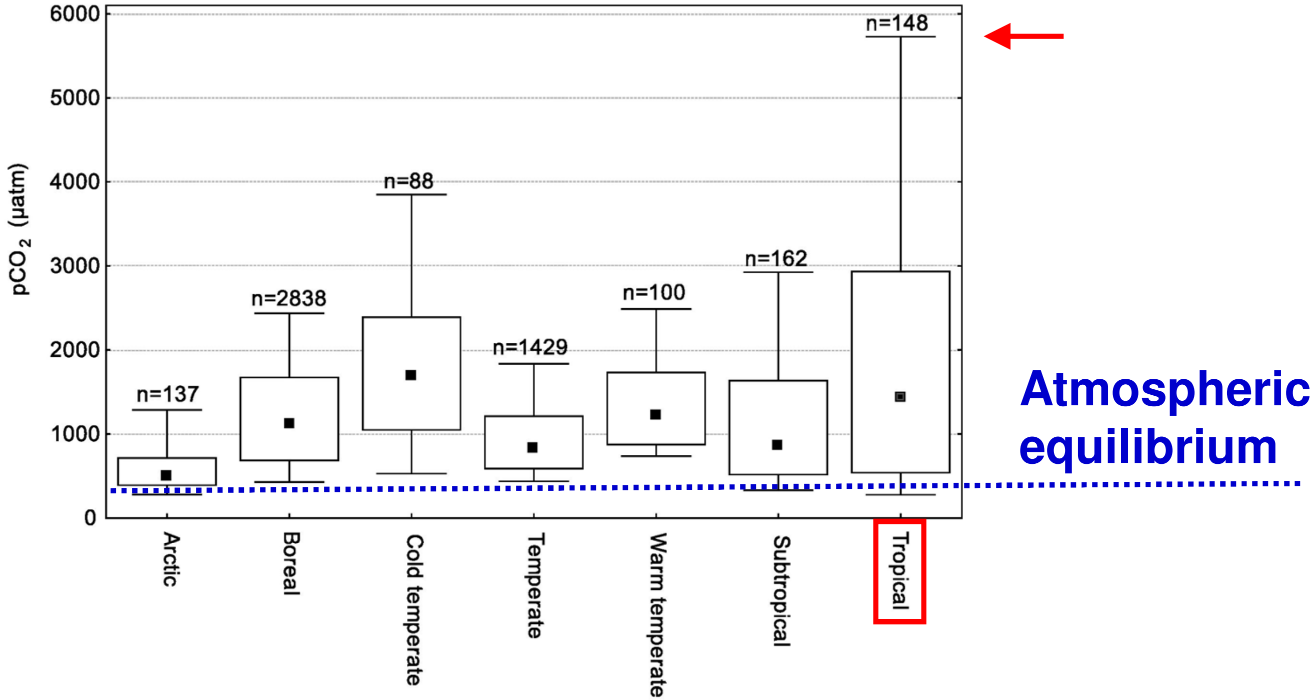


Figure 5. Plot of log pCO_2 against log DOC for 4555 globally distributed lakes with DOC data available. Each point in the plot represents one individual lake. Circles, lakes with a single measurement. Triangles, mean values for lakes with multiple measurements. Solid line, linear regression for all data points in plot ($y = 2.67 + 0.414 \times x$; $R^2 = 0.26$; $p < 0.0001$). See color version of this figure in the HTML.

Sobek et al. (2005) GBC, 19, GB2003, doi:10.1029/2004GB002264

Atmospheric CO_2 fluxes in lakes

Highest CO_2 emission from lakes observed in the tropics



Atmospheric equilibrium

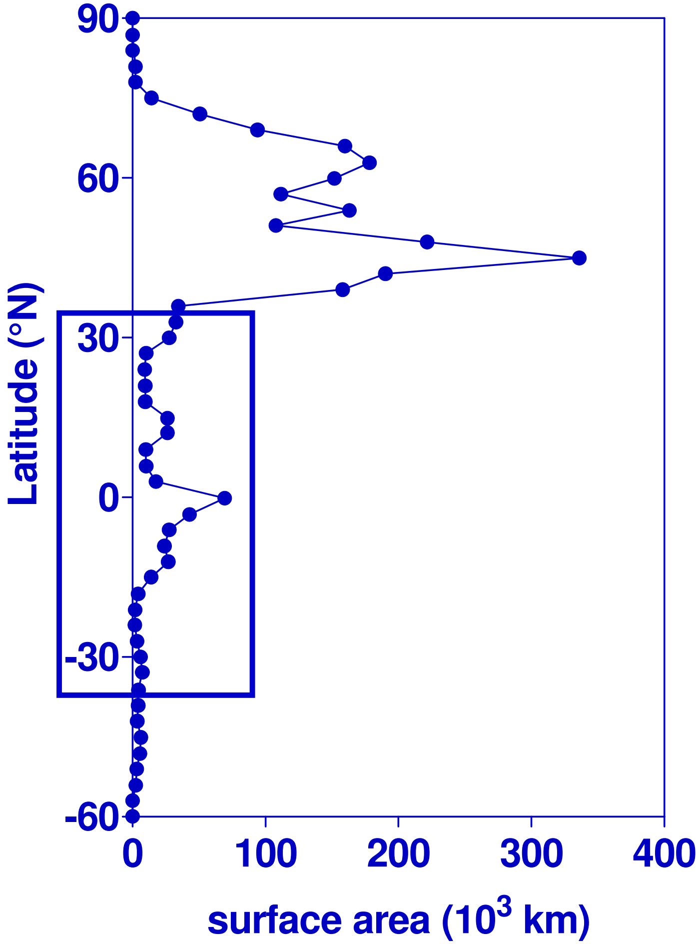
Figure 2. Distribution of pCO_2 in different climatic regions, as defined by latitude (Arctic: >56°; cold temperate: 48°–56°; temperate: 40°–48°; warm temperate: 34°–40°; subtropical: 20°–34°; tropical: 0°–20°). The points depict the median, the boxes show the quartiles, and the whiskers mark the 10% and 90% percentiles. The number of lakes in each climatic region is shown. See color version of this figure in the HTML.

Sobek et al. (2005) GBC, 19, GB2003, doi:10.1029/2004GB002264

Why lake Kivu ?

Tropics and subtropics = 15.7% of total lake surface area

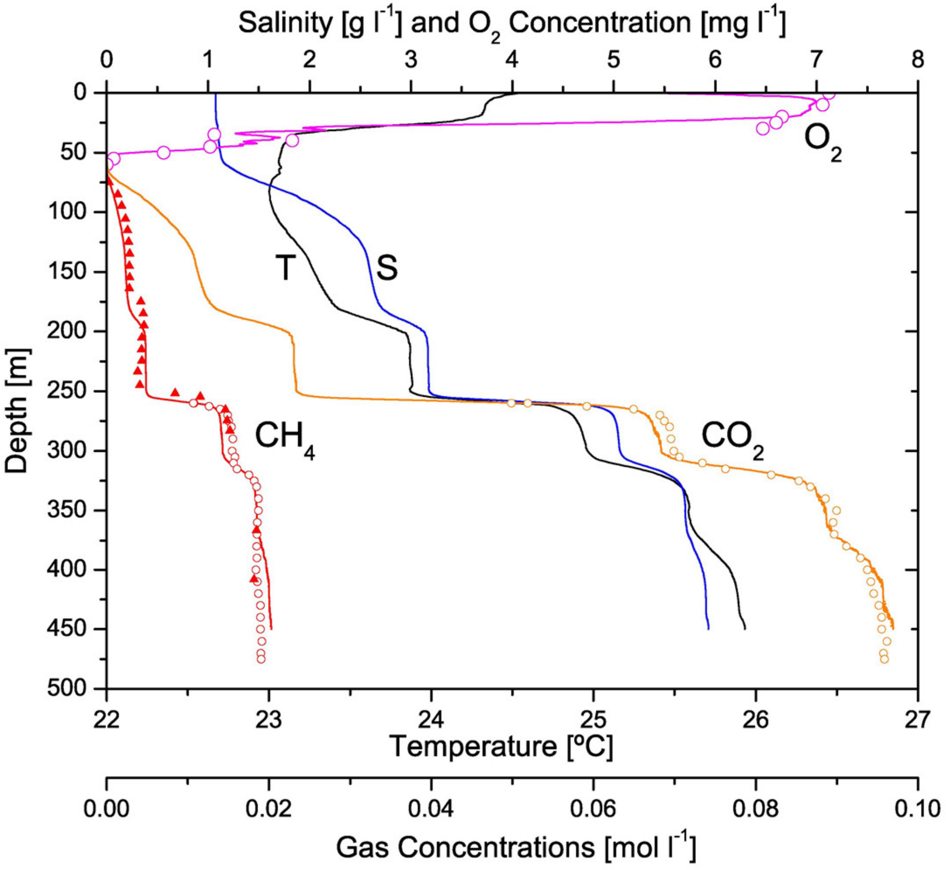
African lakes = 9.3% of total lake surface area
= 0.8% of total of lakes measured for CO_2
= 0.3% of total of measurements for CO_2

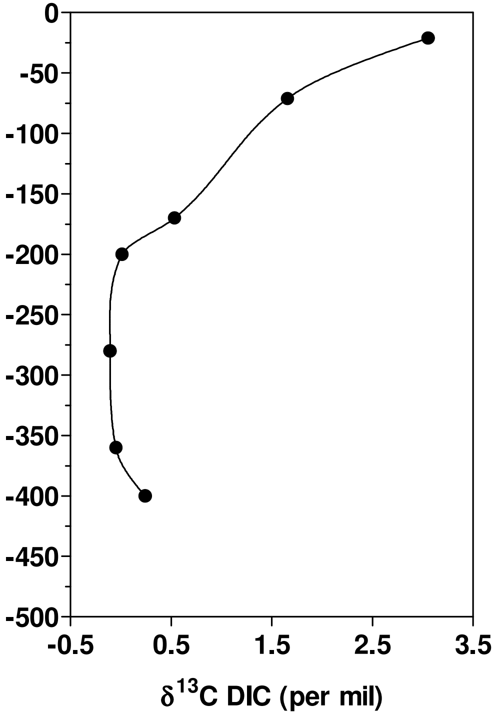


Lehner & Döll (2004) J. Hydrol. 296:1–22

Why lake Kivu ?

Bottom high CO_2, higher temperature and salinity = geothermal inputs
Bottom high CH_4 = degradation at depth of organic matter from surface





Dehairs et al. (unpl.)

Figure 2. Vertical profiles of temperature (T), salinity (S), and dissolved gas concentrations in Lake Kivu in February 2004. The orange line is the CO_2 concentration calculated from pH and alkalinity, the red line is the CH_4 concentration assuming a constant CH_4/CO_2 ratio, the open circles show the gas concentrations measured in November 2003, and the triangles show the CH_4 concentrations measured with the Capsum Mets sensor. The oxygen concentrations measured with the CTD probe and using the Winkler method are shown by the magenta line and the magenta circles, respectively.

Schmid et al. (2005) G3 6(7):doi:10.1029/2004GC000892

Why lake Kivu ?

In bottom waters, increase of CH_4 of 15-20% and CO_2 of 10% in 30 yr

- **Due to increase of primary production and/or sedimentation of organic carbon ?**
  - **Due to eutrophication ?**
  - **Due to removal of *Daphnia curvirostris* due to introduction of sardine *Limnothrissa miodon* ?**

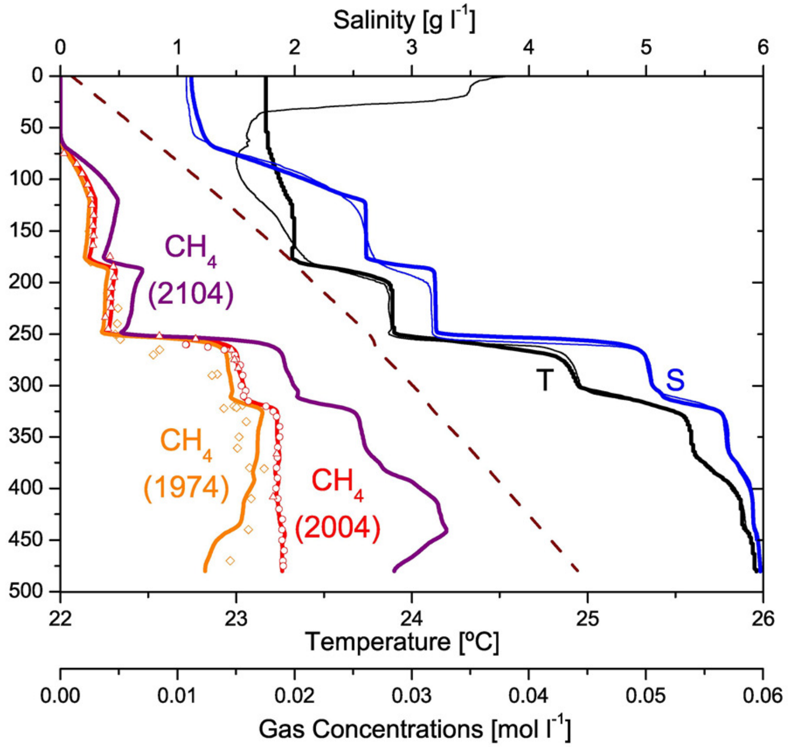
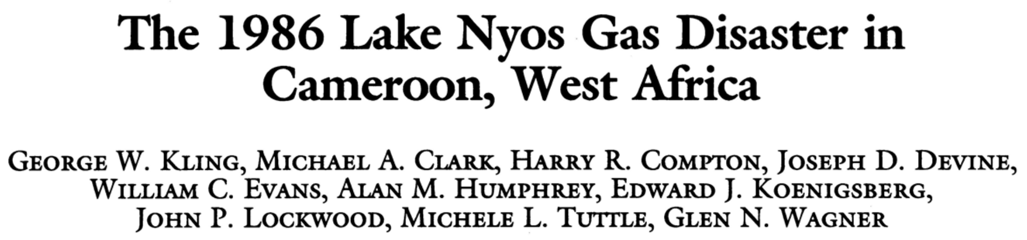


Figure 5. Simulated (thick lines) CH_4 concentrations, temperatures (T), and salinities (S) compared to measurements (thin lines and symbols), and simulated CH_4 concentration in 100 years compared to 80% CH_4 saturation (dashed line).

How will industrial exploitation of CH_4 change nutrient, organic carbon and CO_2 cycling ?

Schmid et al. (2005) G3 6(7):doi:10.1029/2004GC000892

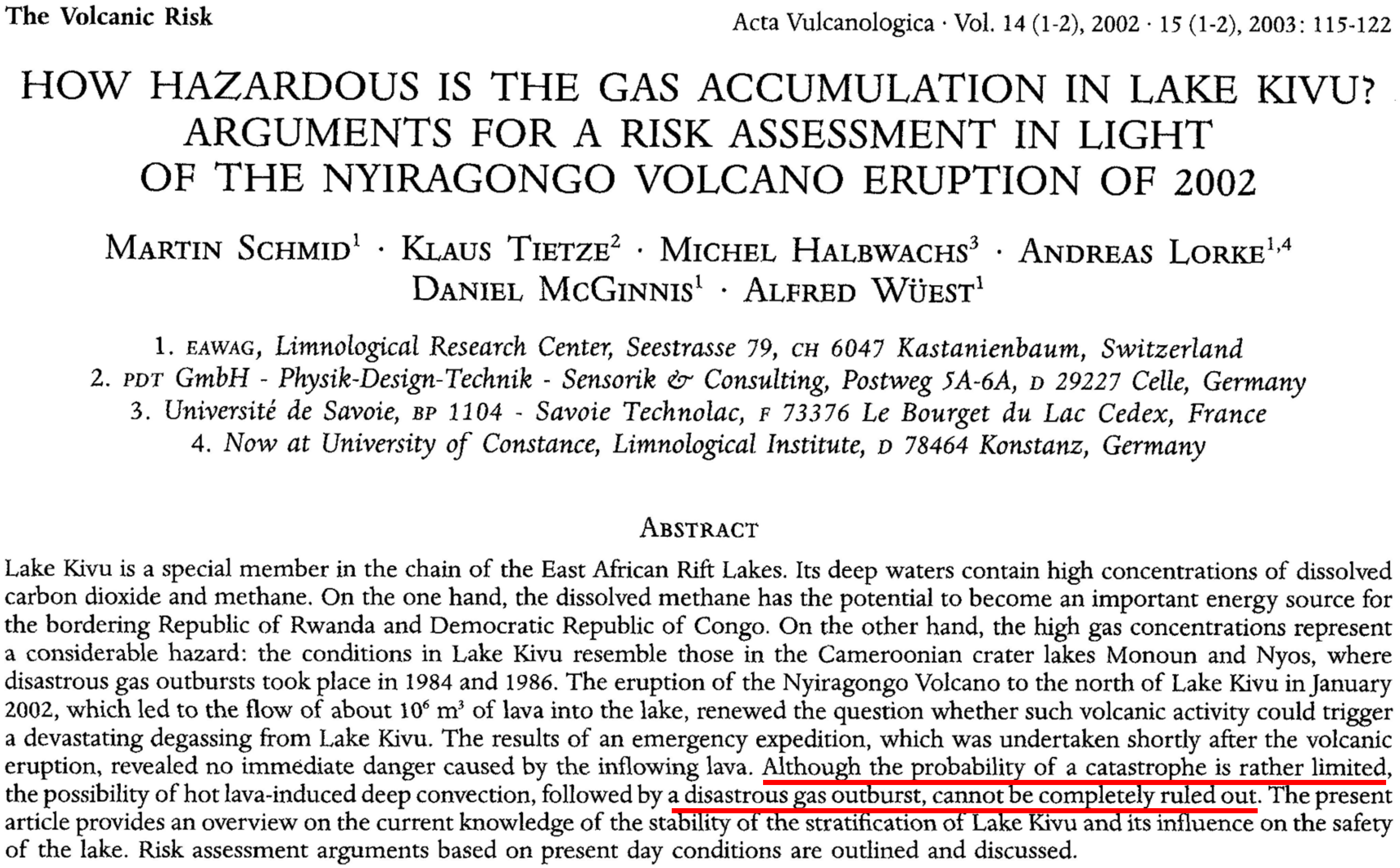
Why lake Kivu ?



The 1986 Lake Nyos Gas Disaster in Cameroon, West Africa

GEORGE W. KLING, MICHAEL A. CLARK, HARRY R. COMPTON, JOSEPH D. DEVINE,
WILLIAM C. EVANS, ALAN M. HUMPHREY, EDWARD J. KOENIGSBERG,
JOHN P. LOCKWOOD, MICHELE L. TUTTLE, GLEN N. WAGNER

Kivu a "killer lake" ?



The Volcanic Risk

Acta Vulcanologica · Vol. 14 (1-2), 2002 · 15 (1-2), 2003: 115-122

HOW HAZARDOUS IS THE GAS ACCUMULATION IN LAKE KIVU? ARGUMENTS FOR A RISK ASSESSMENT IN LIGHT OF THE NYIRAGONGO VOLCANO ERUPTION OF 2002

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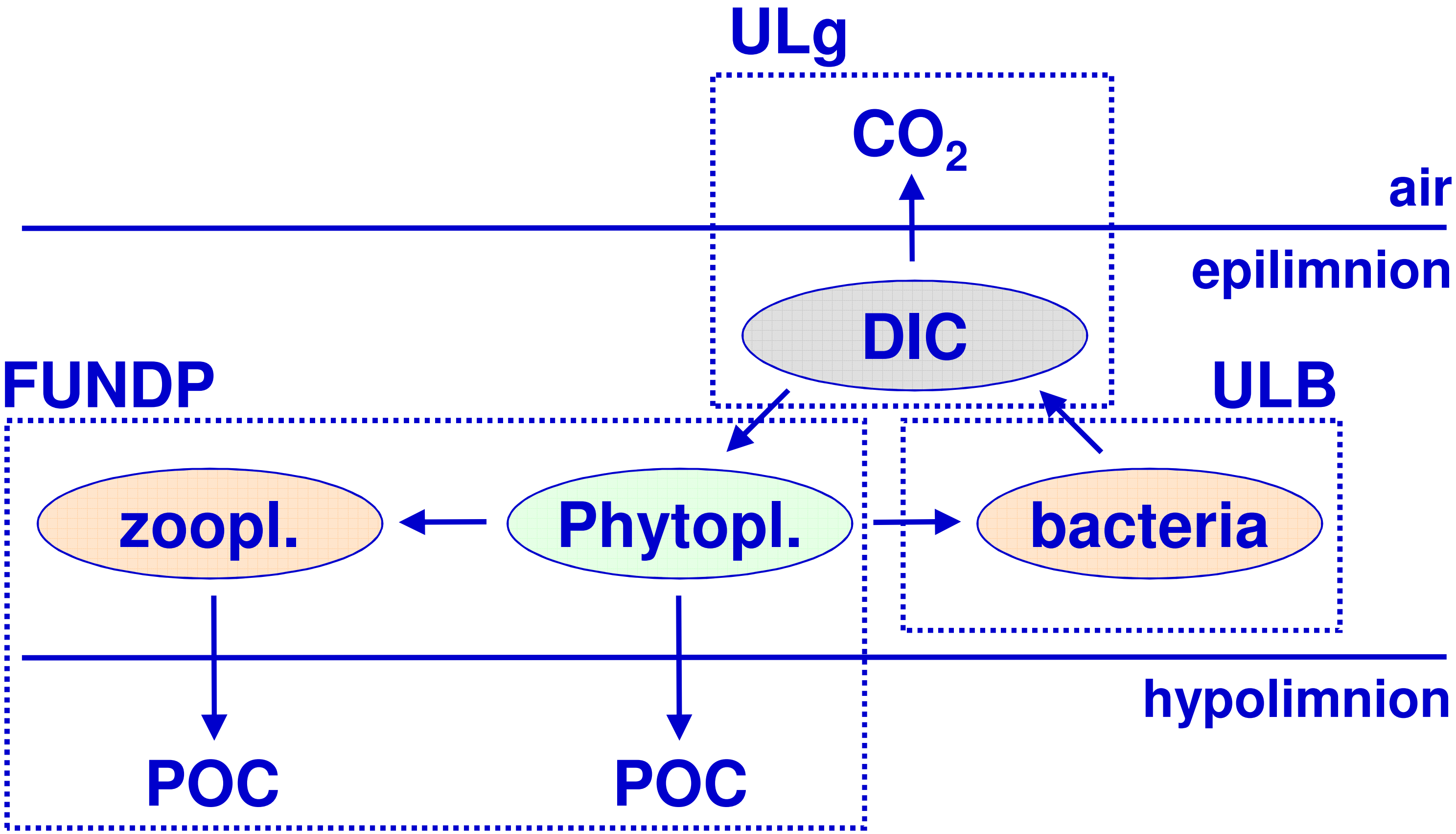
ABSTRACT

Lake Kivu is a special member in the chain of the East African Rift Lakes. Its deep waters contain high concentrations of dissolved carbon dioxide and methane. On the one hand, the dissolved methane has the potential to become an important energy source for the bordering Republic of Rwanda and Democratic Republic of Congo. On the other hand, the high gas concentrations represent a considerable hazard: the conditions in Lake Kivu resemble those in the Cameroonian crater lakes Monoun and Nyos, where disastrous gas outbursts took place in 1984 and 1986. The eruption of the Nyiragongo Volcano to the north of Lake Kivu in January 2002, which led to the flow of about 10^6 m^3 of lava into the lake, renewed the question whether such volcanic activity could trigger a devastating degassing from Lake Kivu. The results of an emergency expedition, which was undertaken shortly after the volcanic eruption, revealed no immediate danger caused by the inflowing lava. Although the probability of a catastrophe is rather limited, the possibility of hot lava-induced deep convection, followed by a disastrous gas outburst, cannot be completely ruled out. The present article provides an overview on the current knowledge of the stability of the stratification of Lake Kivu and its influence on the safety of the lake. Risk assessment arguments based on present day conditions are outlined and discussed.

CAKI

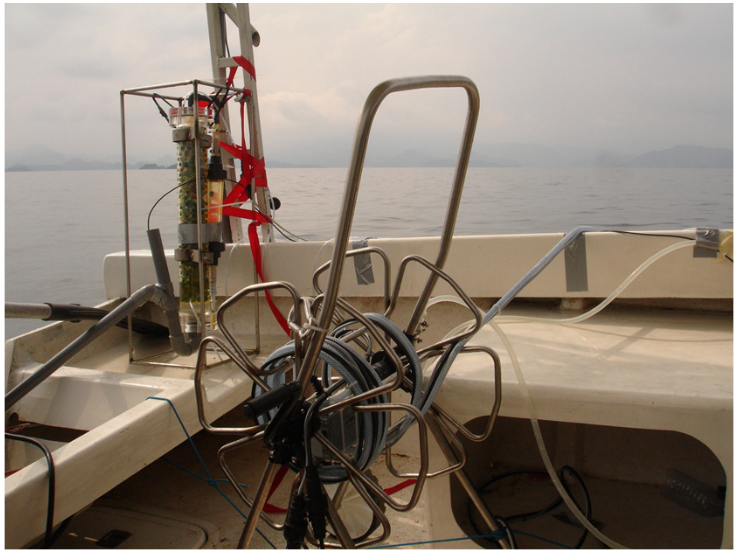
Carbon and Nutrient cycles in lake Kivu (CAKI)

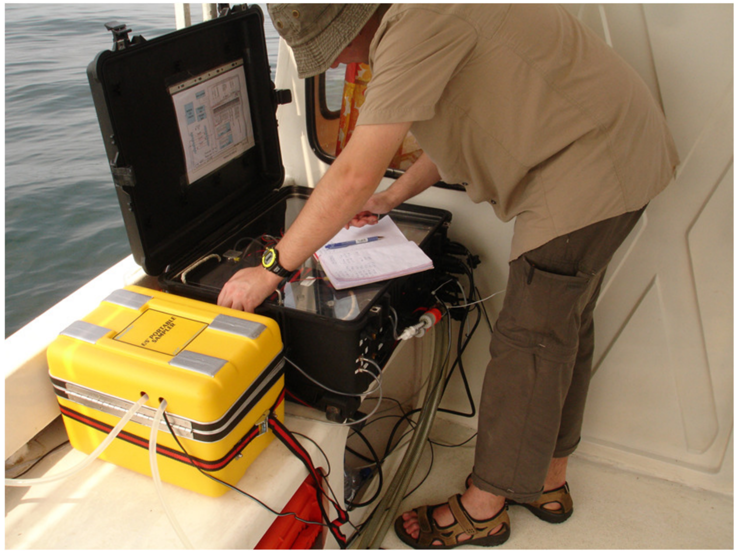
FNRS funded

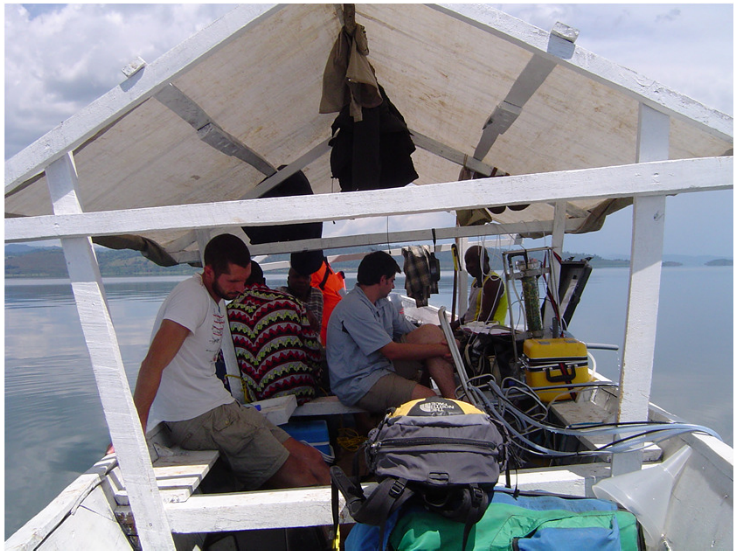


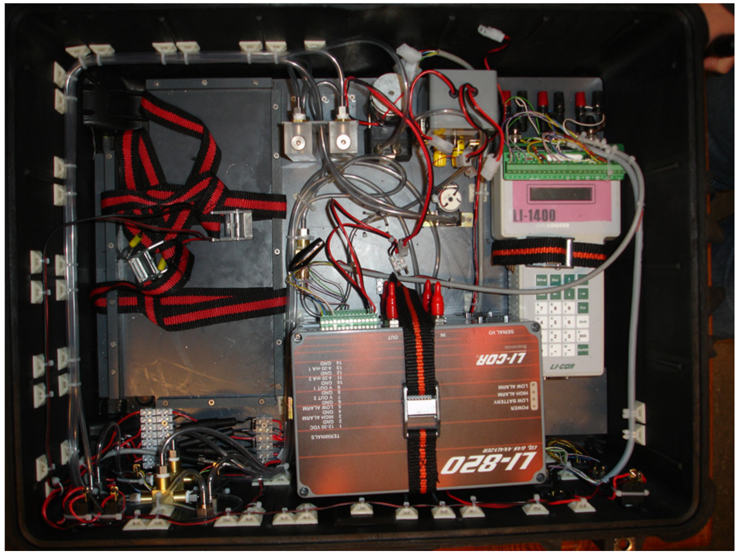
$\delta^{13}C$ DIC measurements : S. Bouillon / F. Dehairs / J.J. Middelburg
CH_4 measurements : G. Abril
Zooplankton, nutrients measurements : ISP (RDC) & UNR (Rwanda)

Preliminary results from the first cruise (15-29 March 2007)







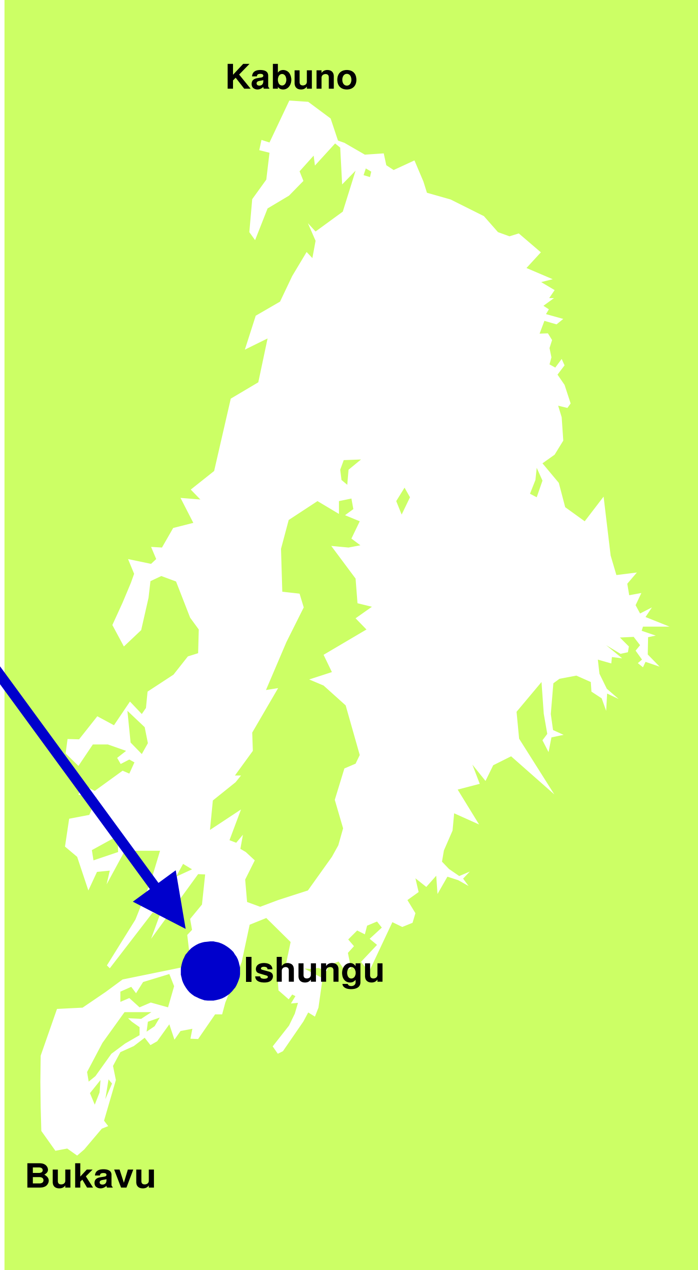


Daily variations of pCO_2 in surface waters

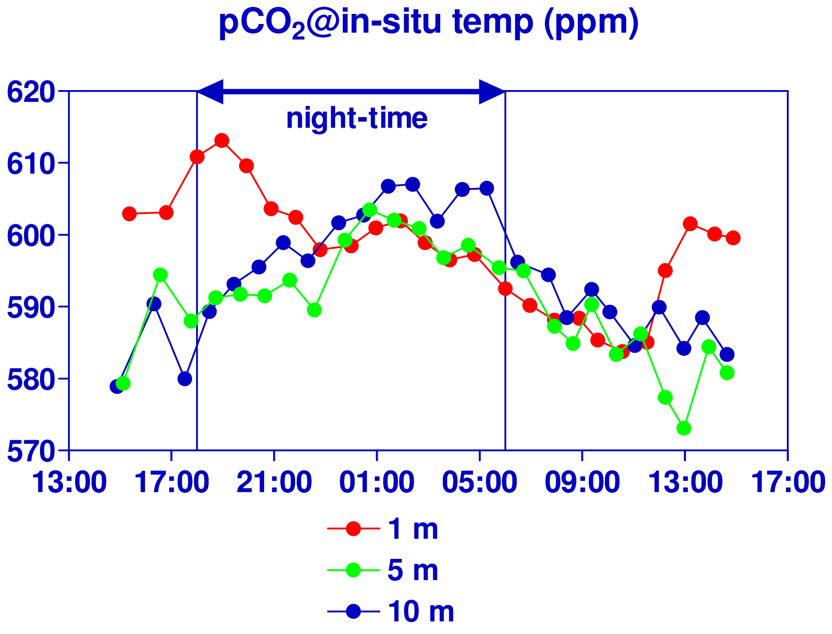
Daily variations in surface waters

pCO_2, temperature, salinity and $\%O_2$ during 24 h at hourly intervals
1m, 5m, 10m, 20m

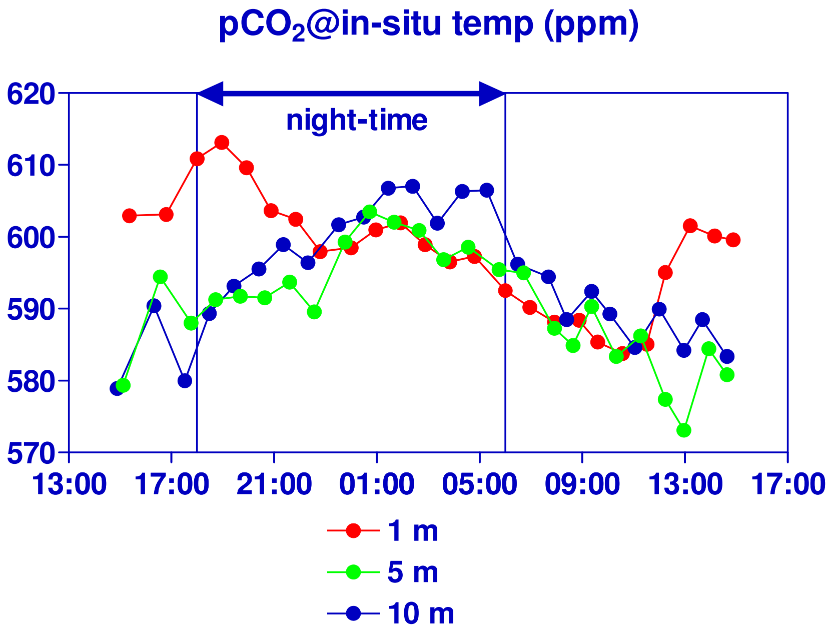
Tiring at times…

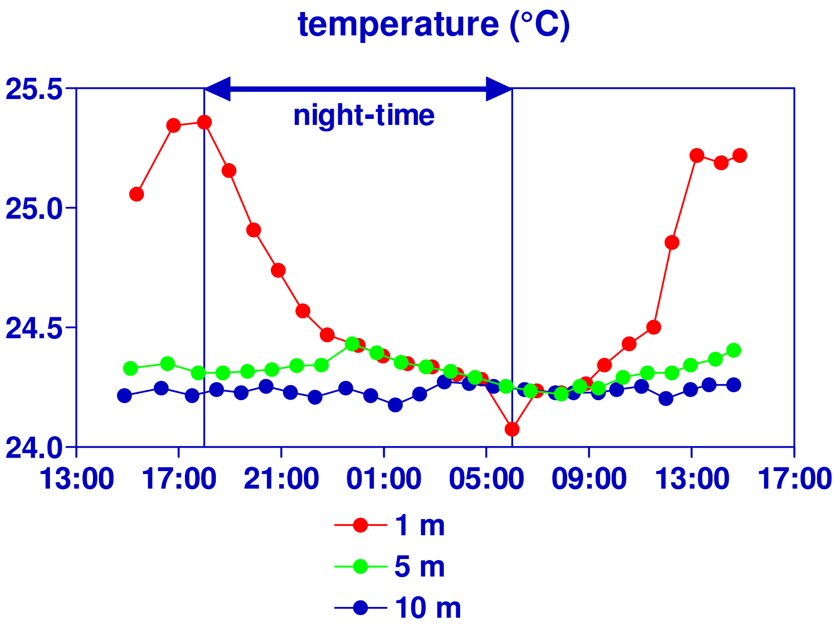


Daily variations in surface waters

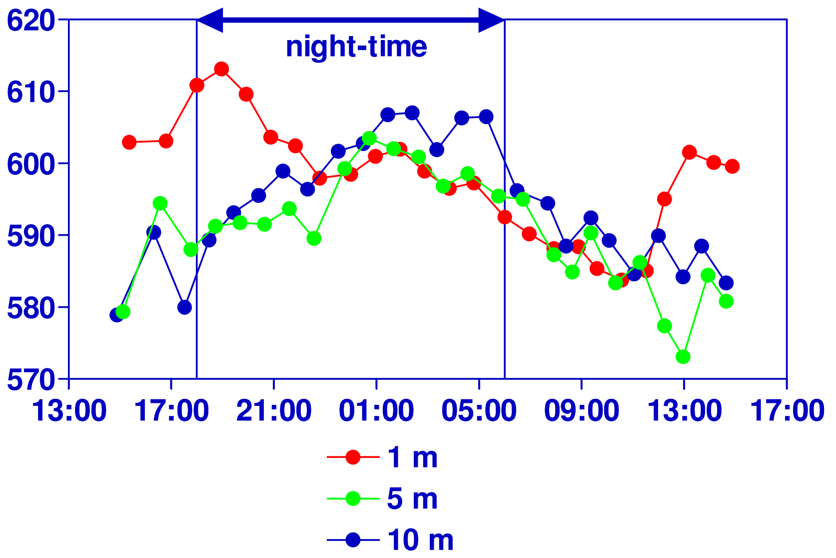


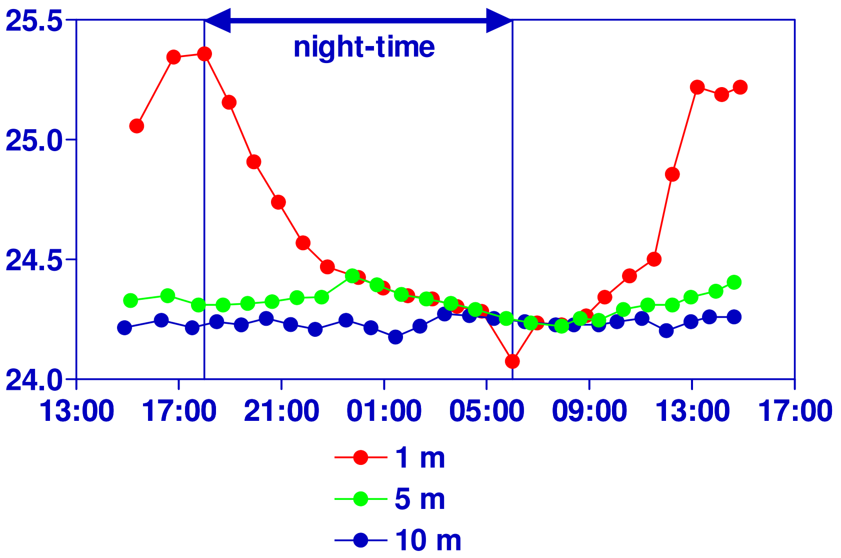
Daily variations in surface waters

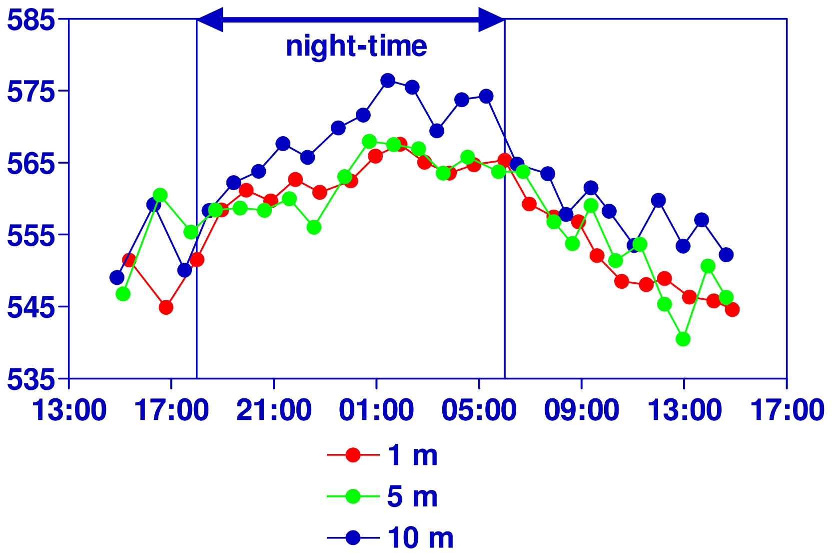




Daily variations in surface waters

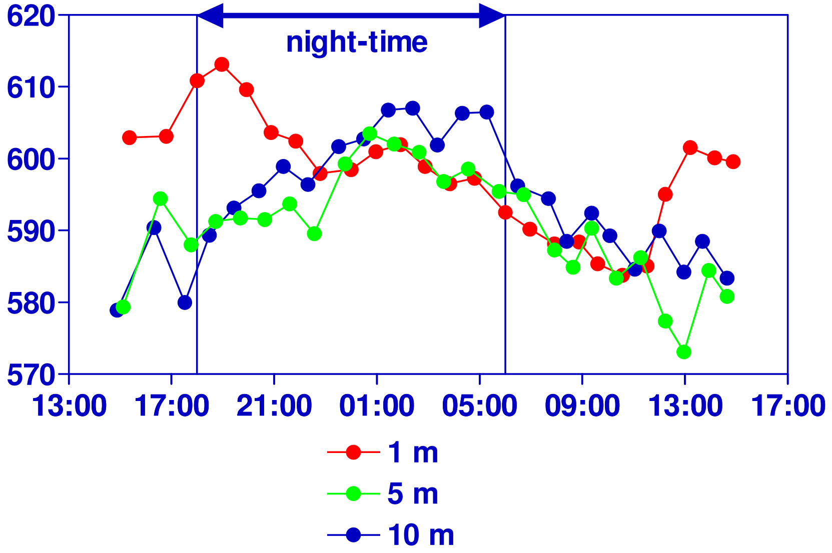

pCO$_2$@in-situ temp (ppm)


temperature (°C)

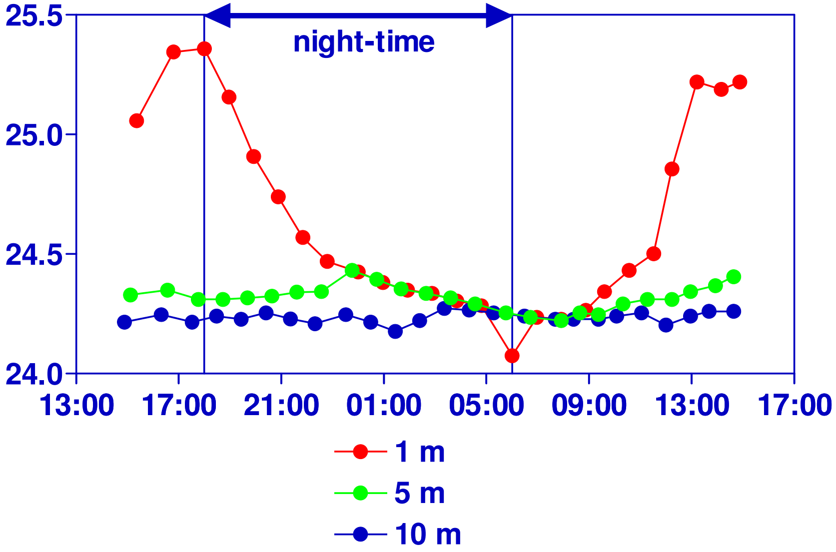

pCO$_2$@23°C (ppm)

Daily variations in surface waters

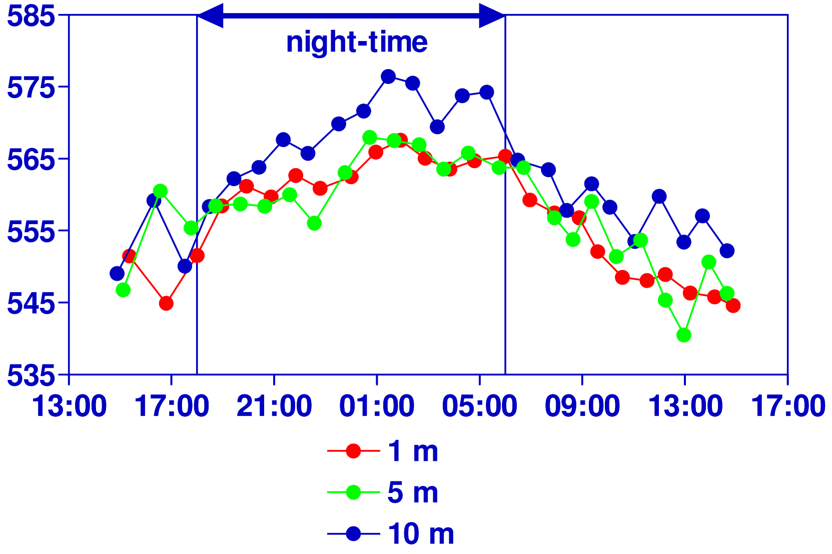
pCO$_2$@in-situ temp (ppm)



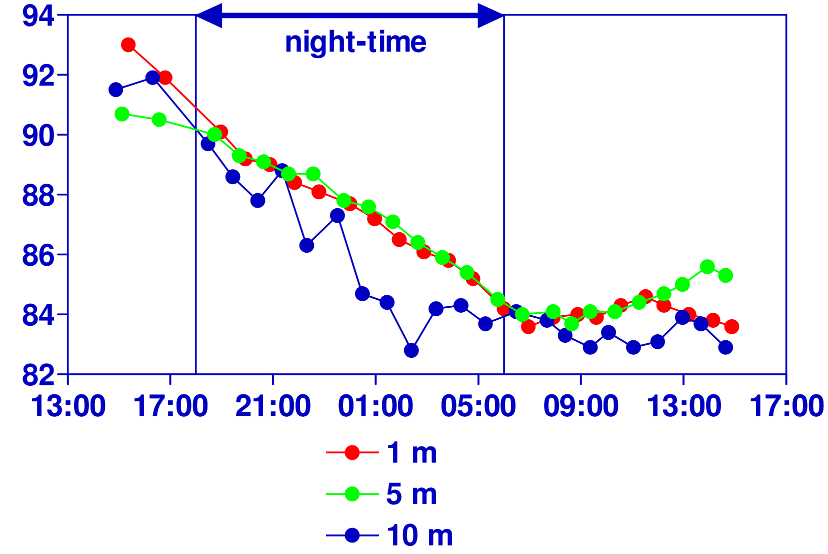
temperature (°C)



pCO$_2$@23°C (ppm)

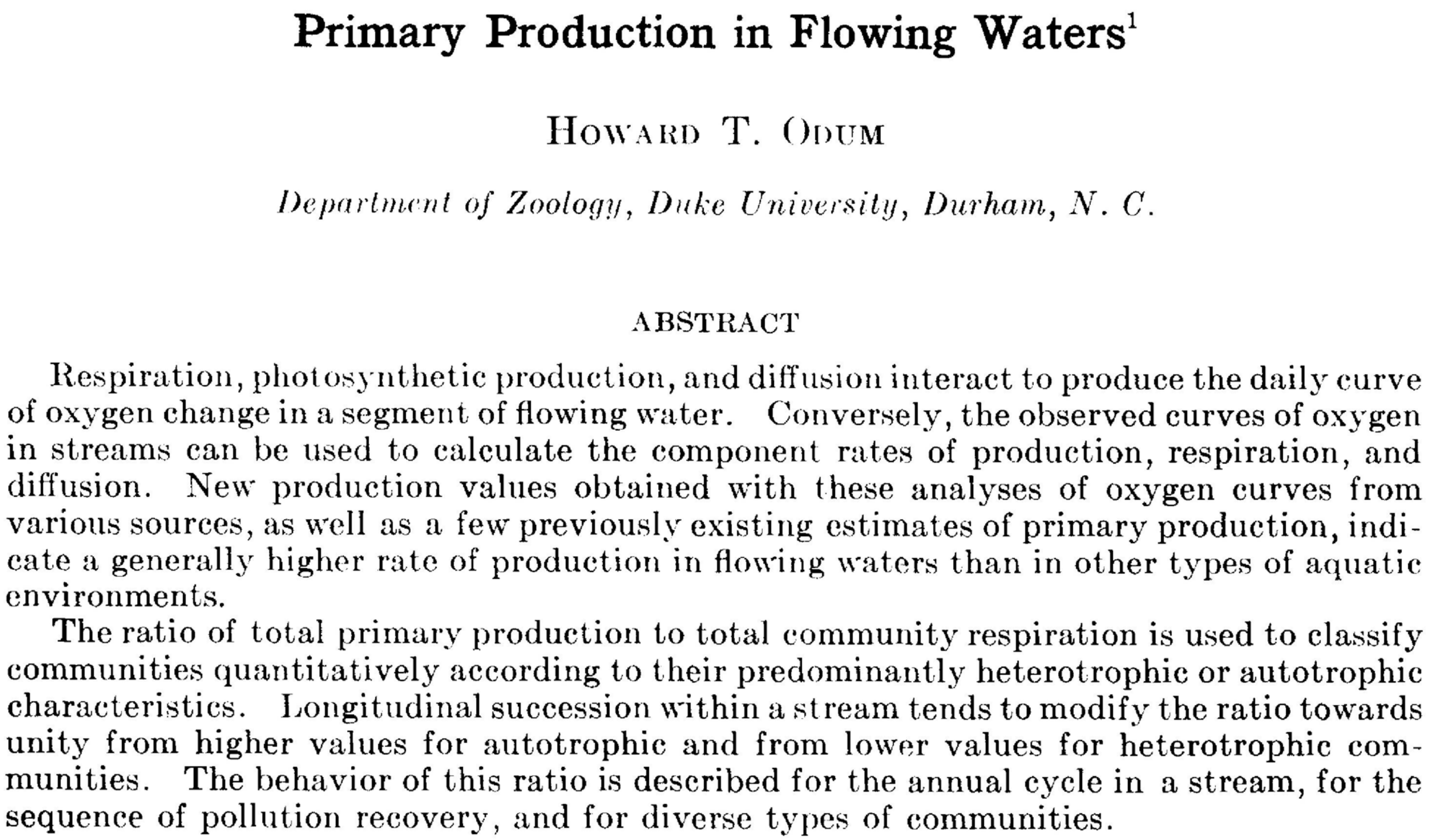


%O$_2$ (%)



Daily variations in surface waters

Next step : computation of metabolic process rates (gross primary production, community respiration), by mass balance of CO_2



Primary Production in Flowing Waters[1]

HOWARD T. ODUM

Department of Zoology, Duke University, Durham, N. C.

ABSTRACT

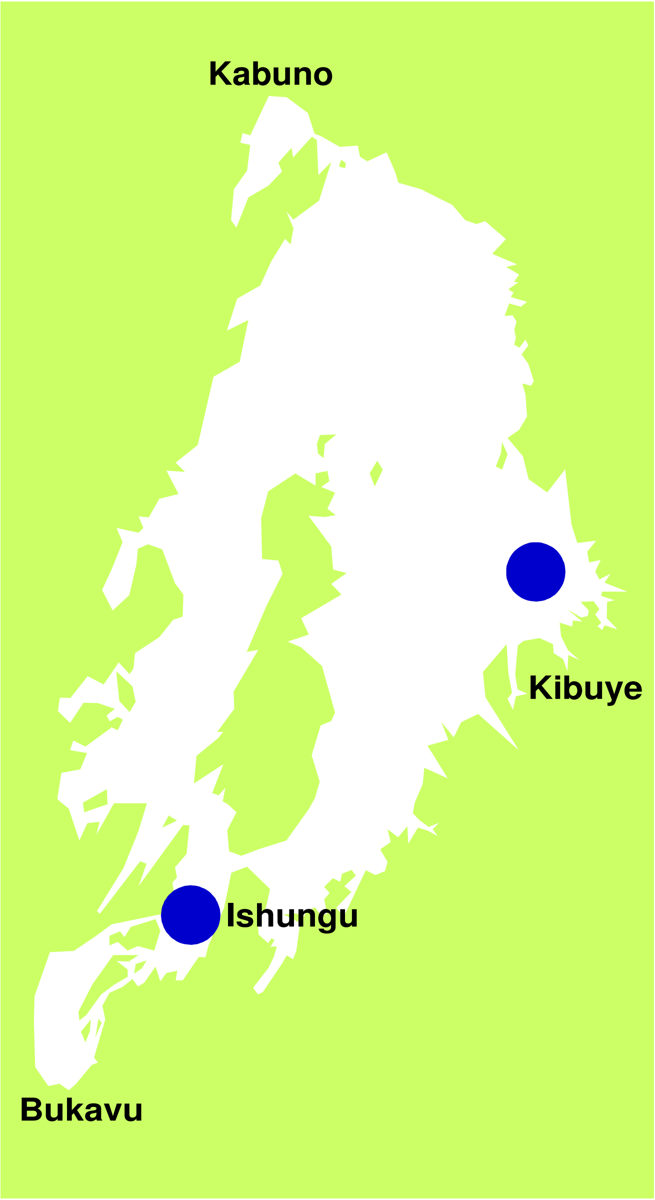
Respiration, photosynthetic production, and diffusion interact to produce the daily curve of oxygen change in a segment of flowing water. Conversely, the observed curves of oxygen in streams can be used to calculate the component rates of production, respiration, and diffusion. New production values obtained with these analyses of oxygen curves from various sources, as well as a few previously existing estimates of primary production, indicate a generally higher rate of production in flowing waters than in other types of aquatic environments.

The ratio of total primary production to total community respiration is used to classify communities quantitatively according to their predominantly heterotrophic or autotrophic characteristics. Longitudinal succession within a stream tends to modify the ratio towards unity from higher values for autotrophic and from lower values for heterotrophic communities. The behavior of this ratio is described for the annual cycle in a stream, for the sequence of pollution recovery, and for diverse types of communities.

Spatial variability in surface waters

Spatial variability

Net particulate primary production (NPPP) and bacterial respiration (BR)



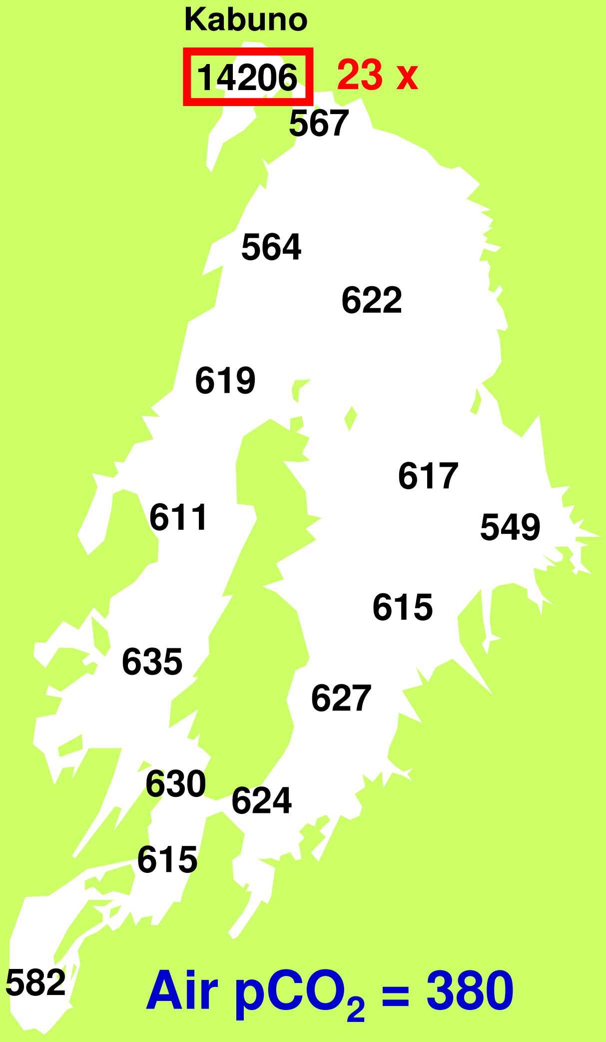
NPPP = 639 mgC m^{-2} d^{-1}
BR = 710 mgC m^{-2} d^{-1}

NPPP = 548 mgC m^{-2} d^{-1}
BR = 1282 mgC m^{-2} d^{-1}

FUNDP & ULB data

Spatial variability

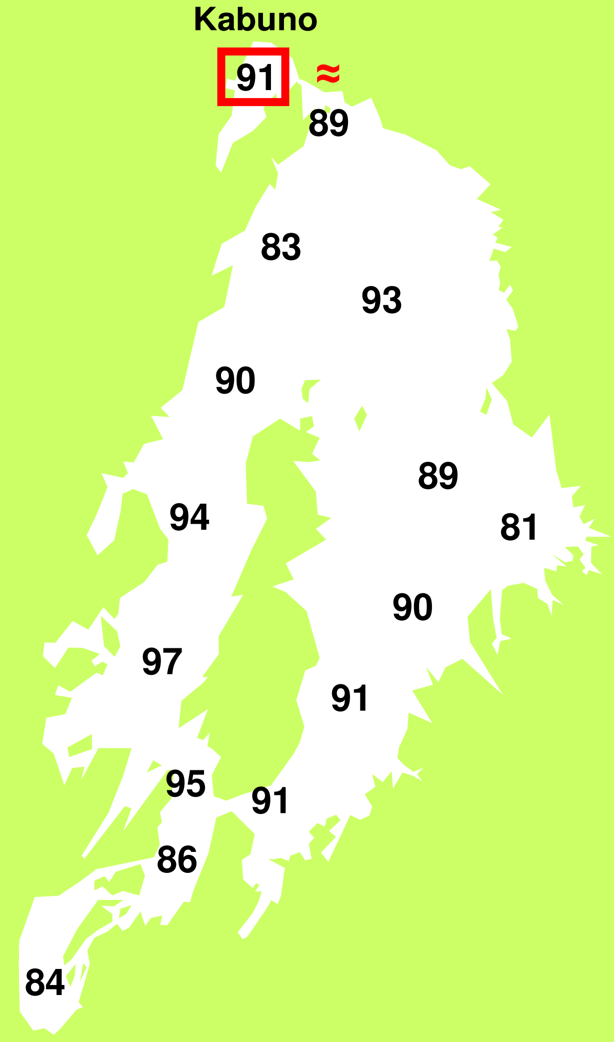
pCO_2 (ppm)



Air pCO_2 = 380

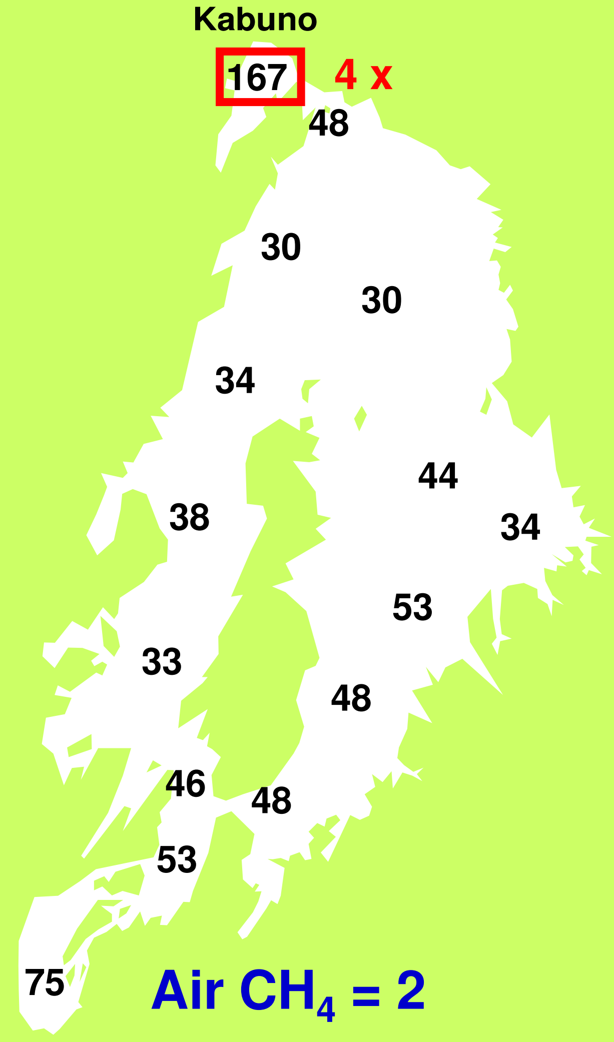
Variability of ± 5%

$\%O_2$ (%)



Variability of ± 5%

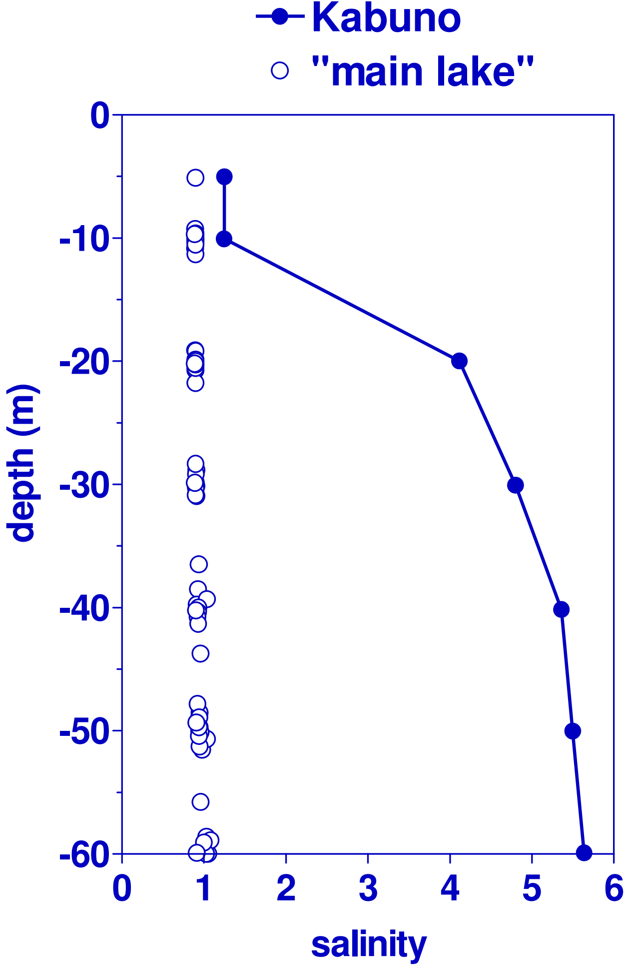
CH_4 (nM)



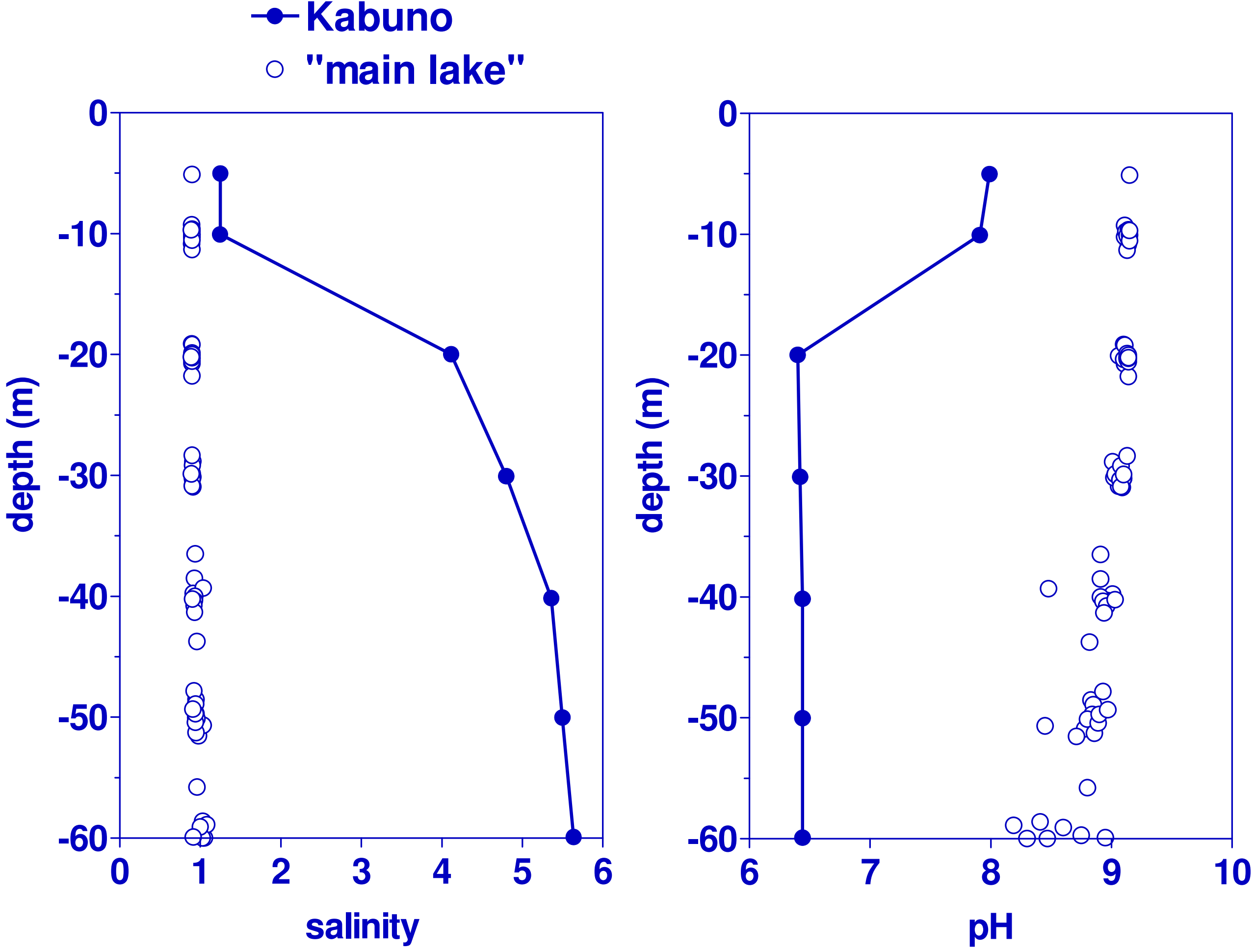
Air CH_4 = 2

Variability of ± 27%

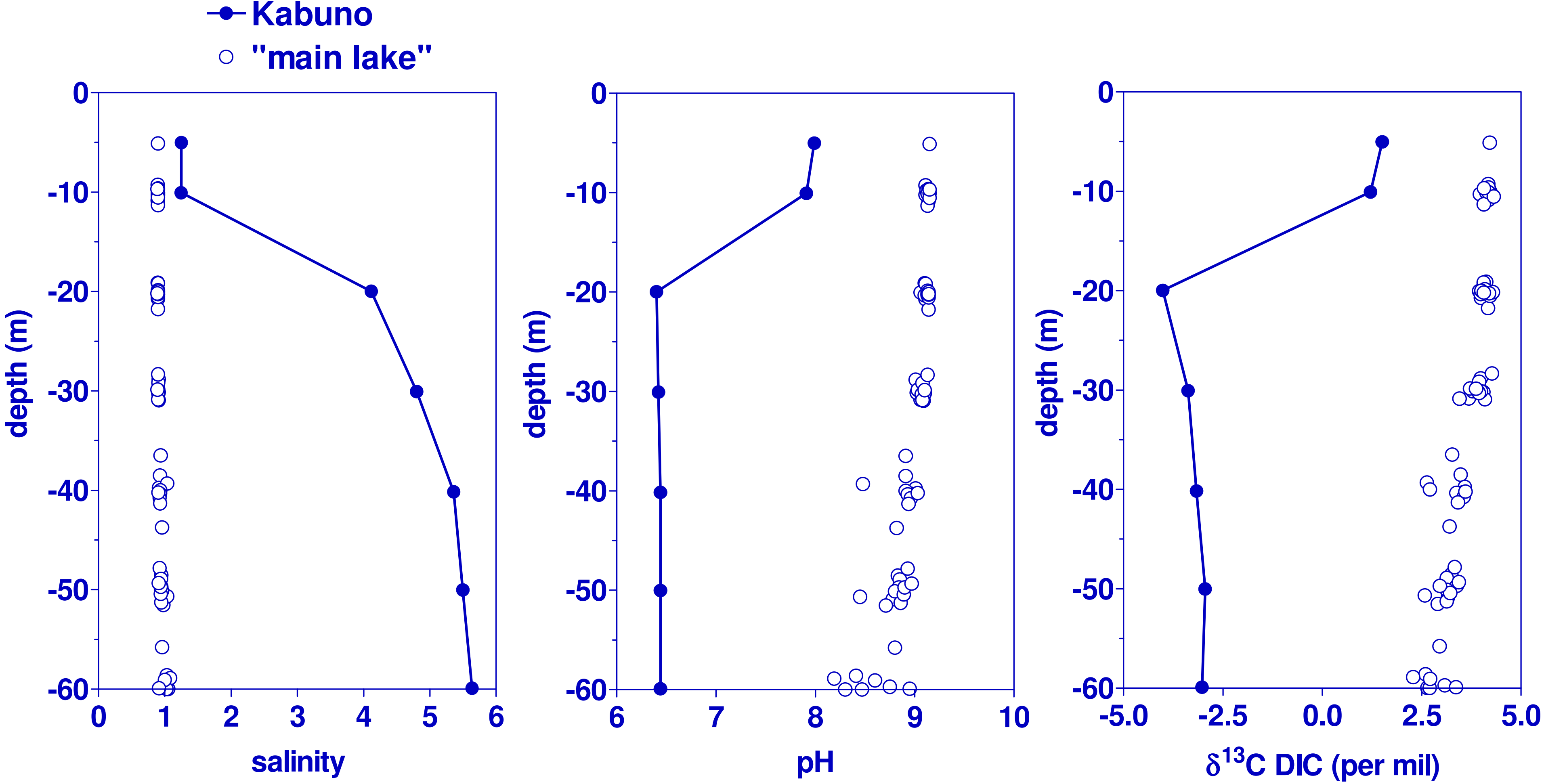
Spatial variability



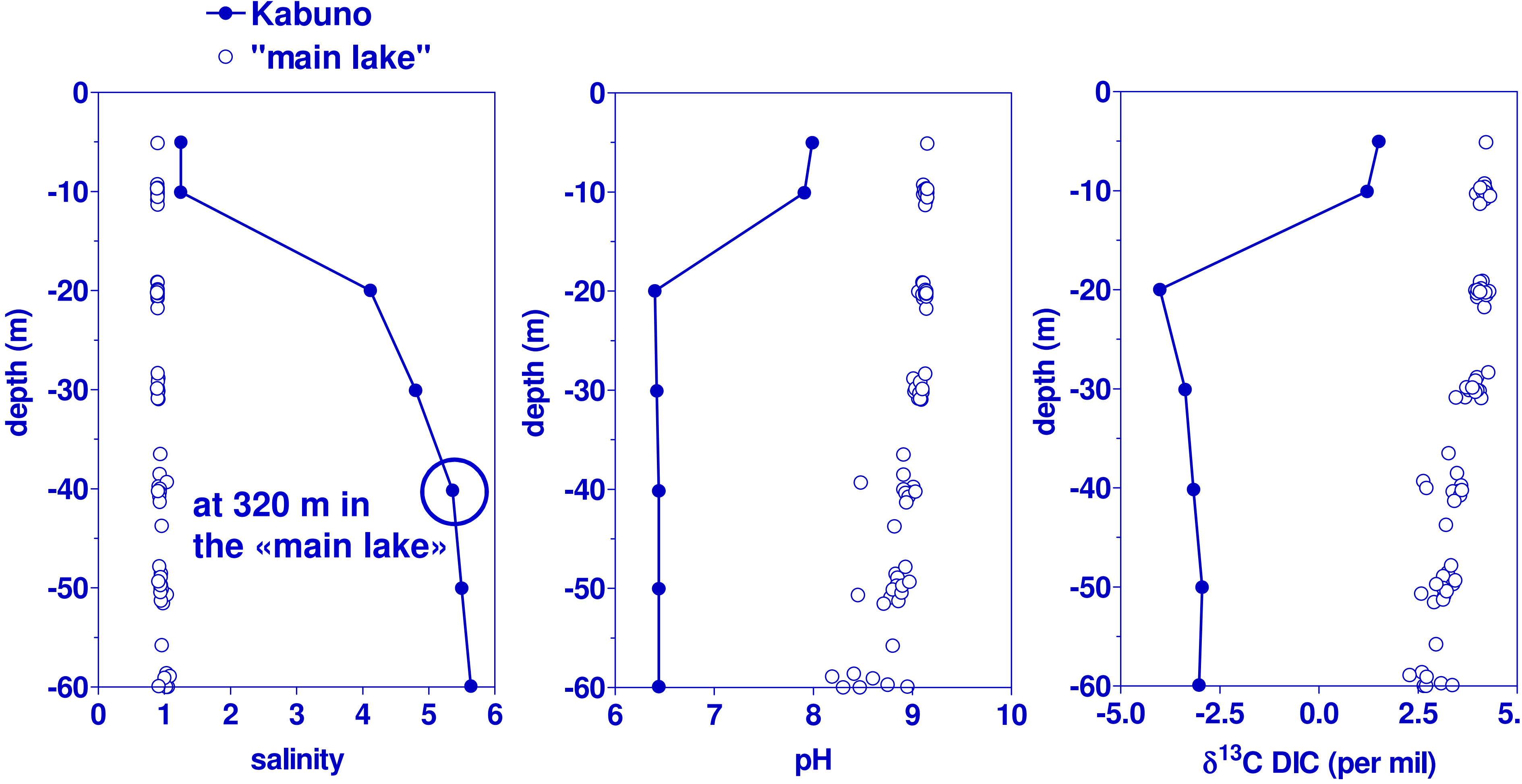
Spatial variability



Spatial variability

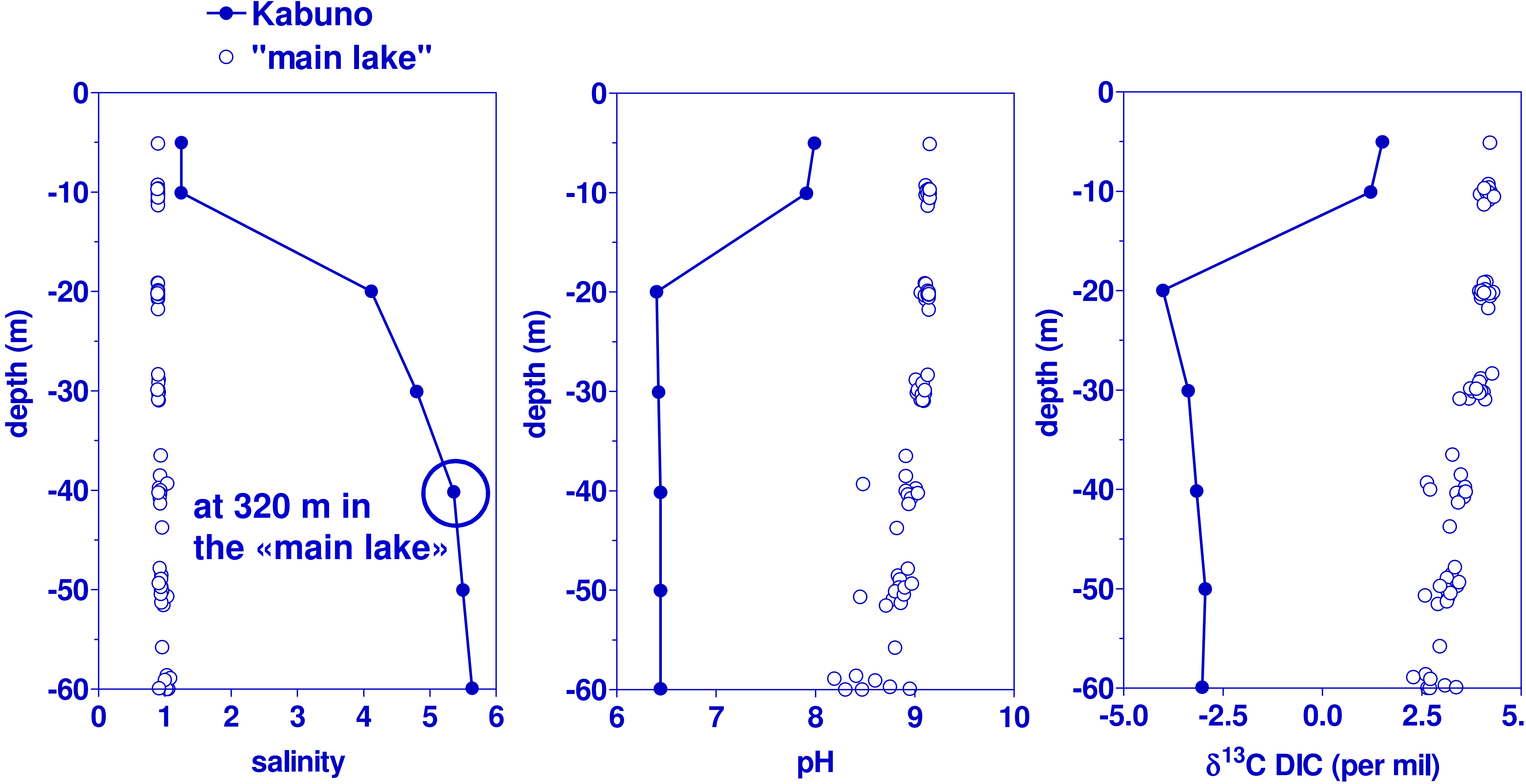


Spatial variability



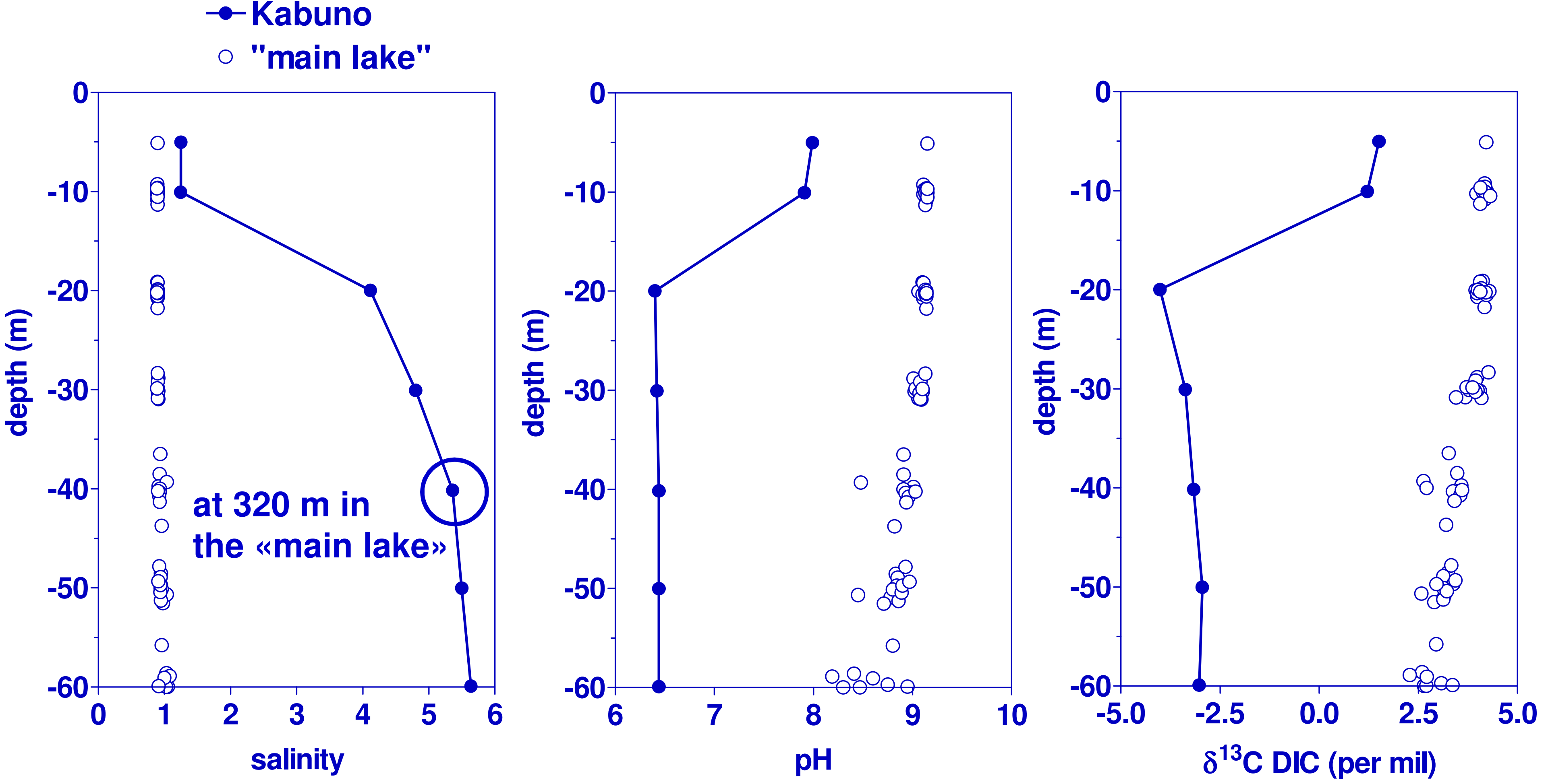
at 320 m in
the «main lake»

Spatial variability



Suggests a much larger contribution of geothermal inputs to whole water column including <u>surface</u> water, and to dynamics of inorganic C chemistry in Kabuno bassin than rest of Kivu lake.

Spatial variability

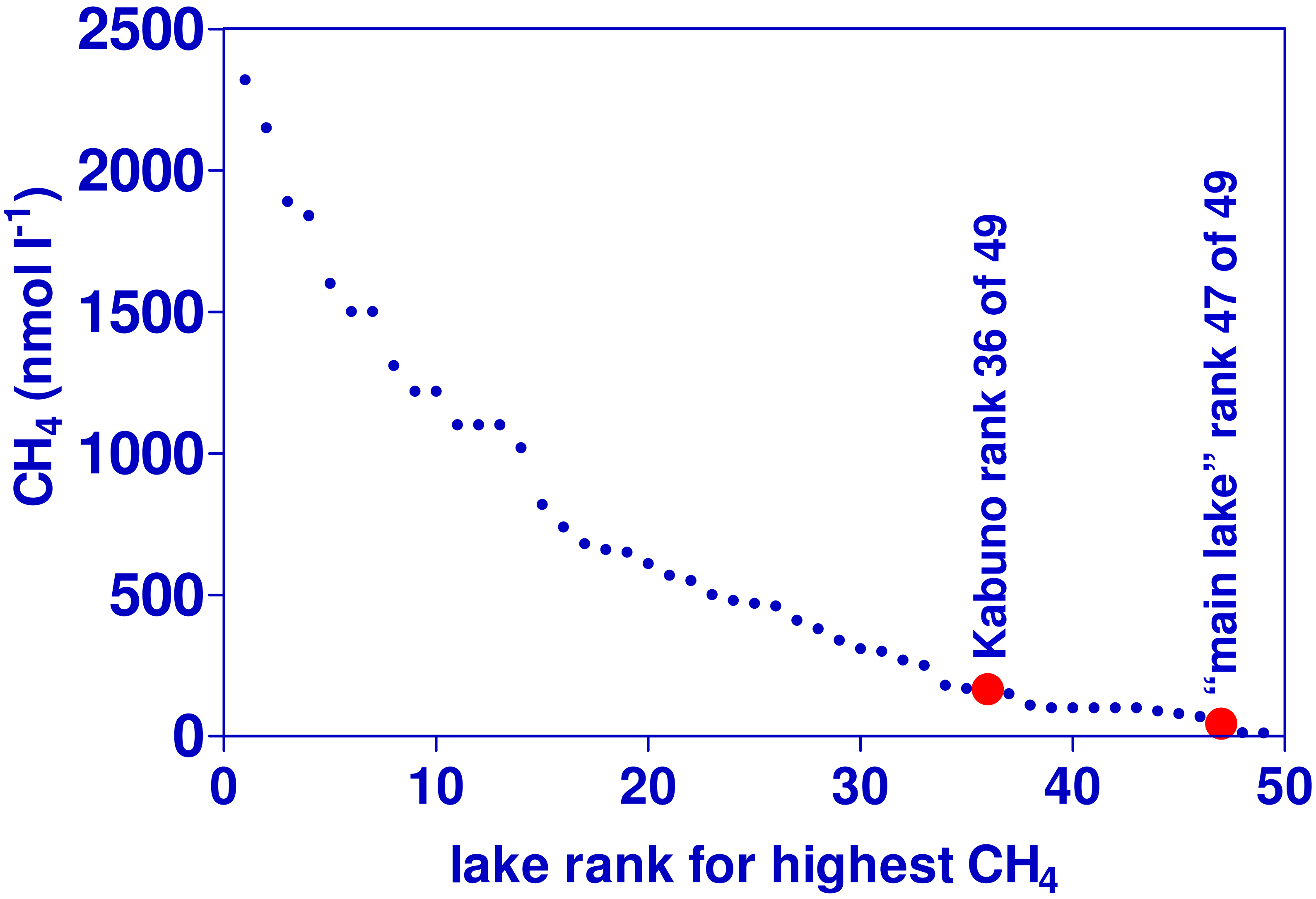


Suggests a much larger contribution of geothermal inputs to whole water column including <u>surface</u> water, and to dynamics of inorganic C chemistry in Kabuno bassin than rest of Kivu lake.

Kabuno is shallower (100m), receives no river water and exchanges little water with Kivu lake (connexion 10 m deep).

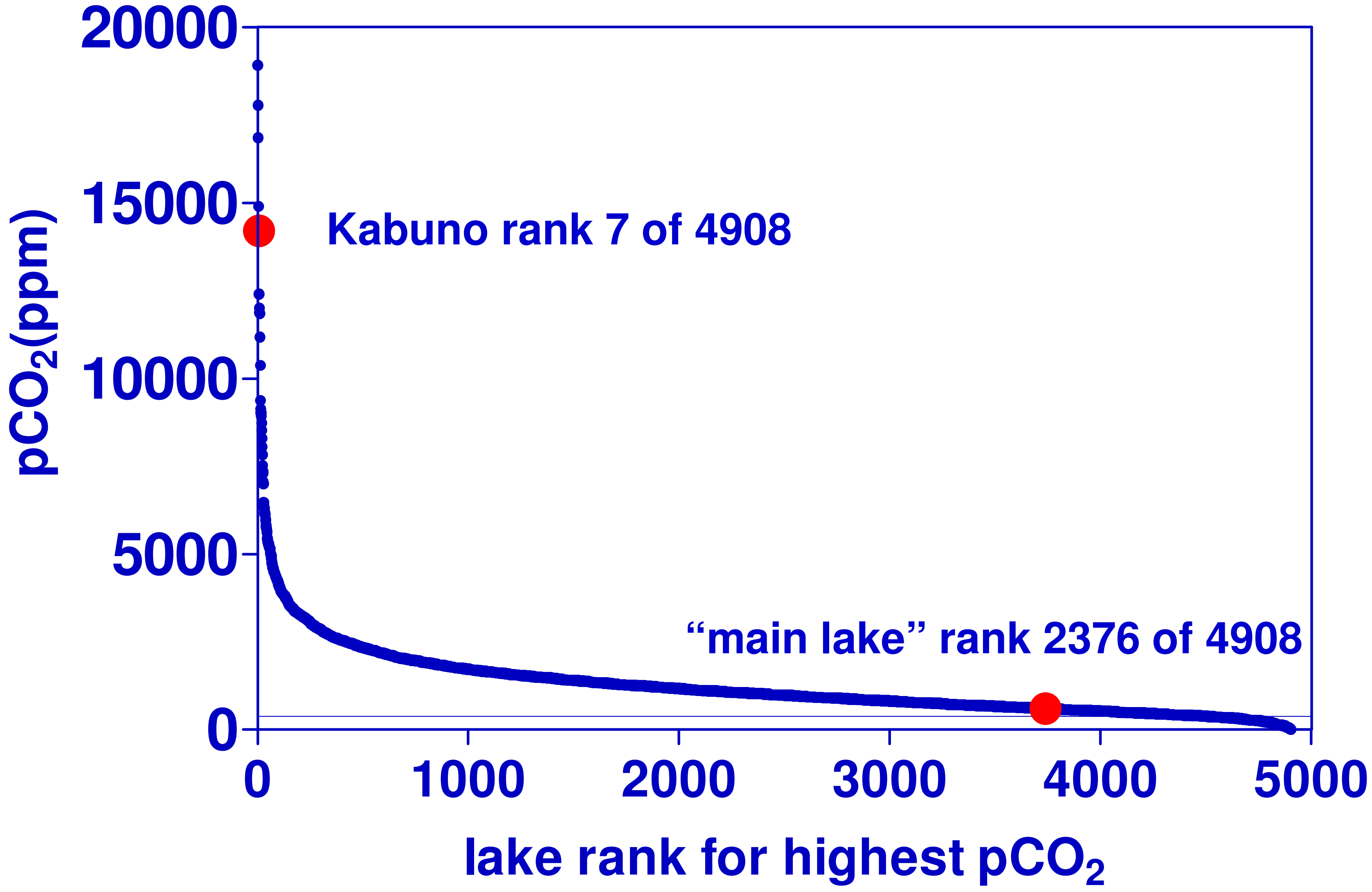
Comparison with other lakes

Surface CH_4 Global comparison



Other CH_4 data from Bastviken et al. (2004) GBC, 18, GB4009

Surface pCO$_2$ Global comparison



Other pCO$_2$ data from Sobek et al. (2005) GBC, 19, GB2003

Surface pCO$_2$ Global comparison

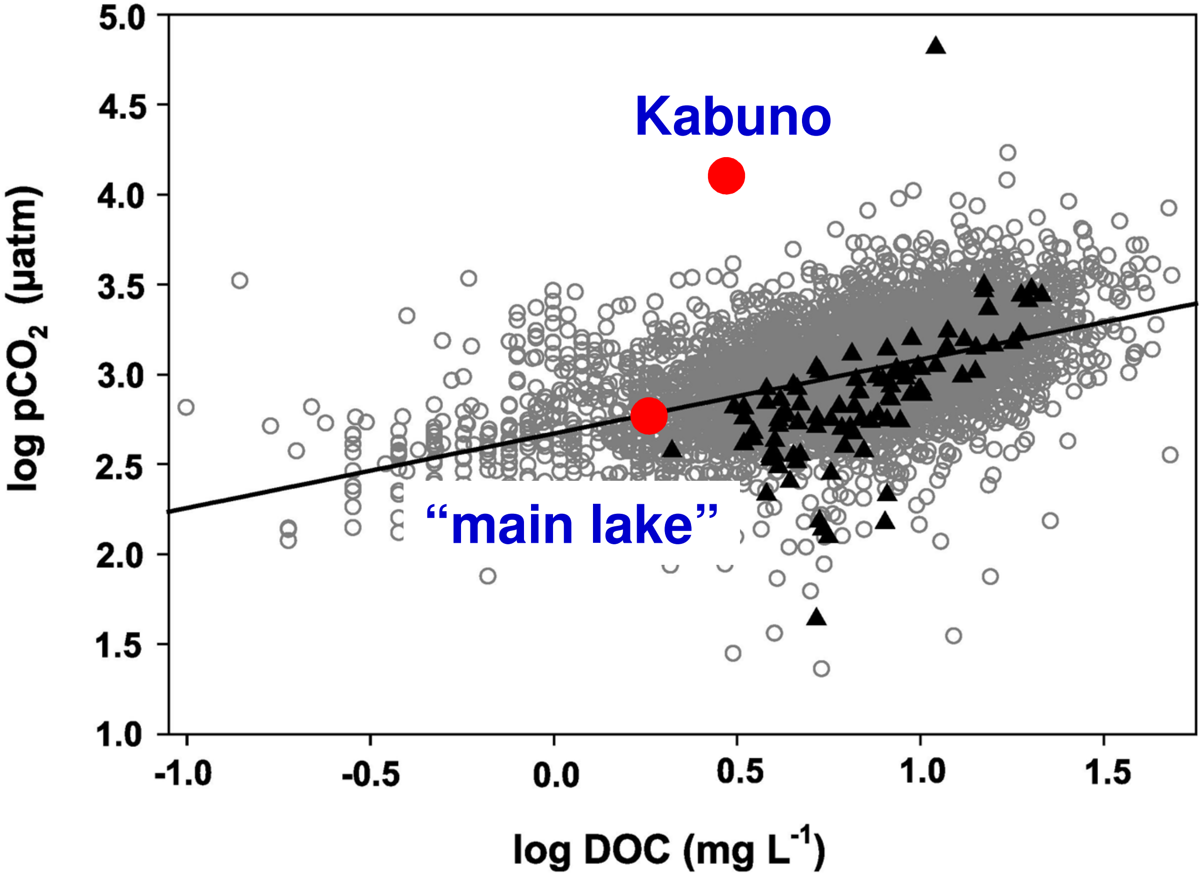
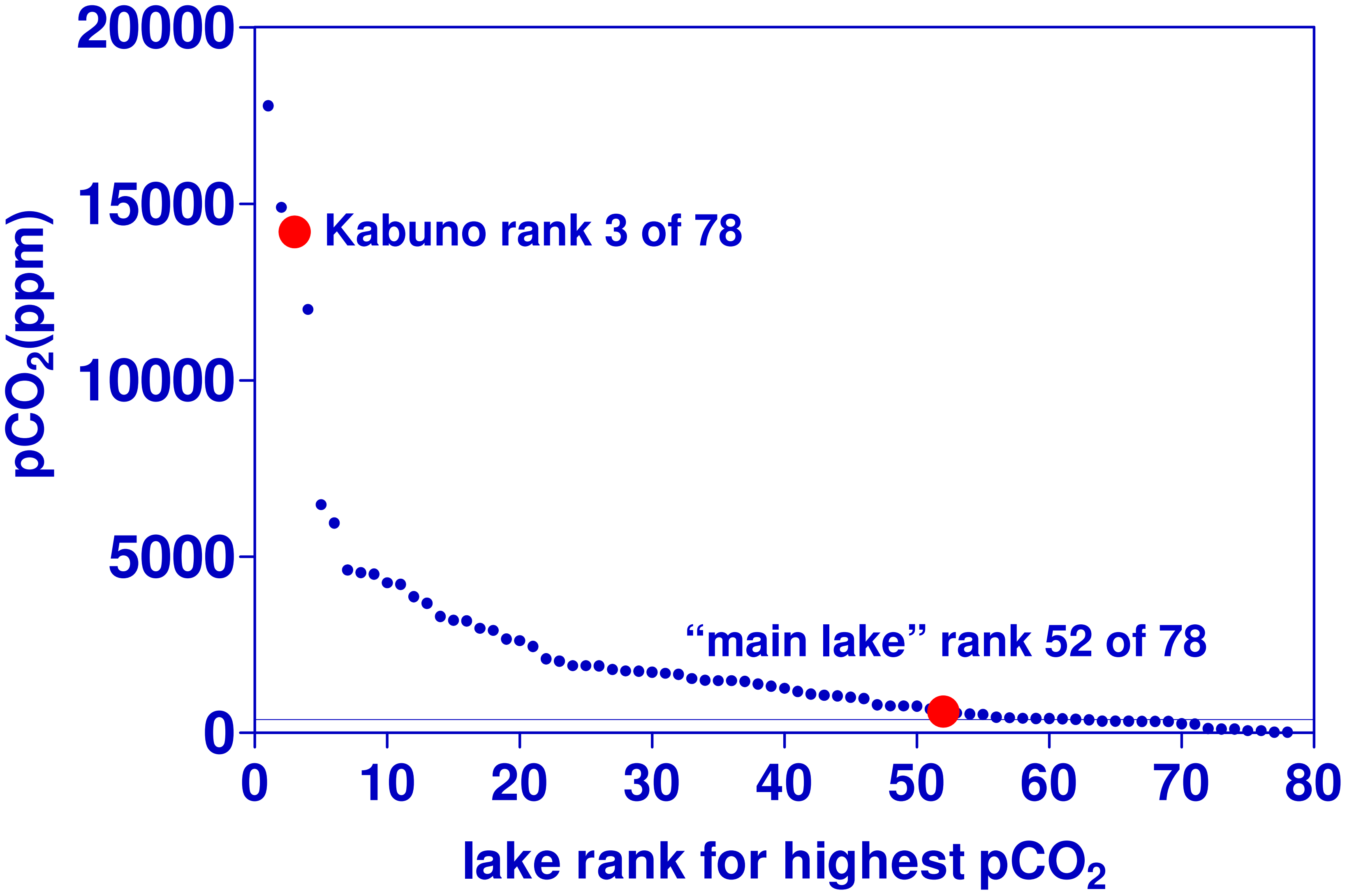


Figure 5. Plot of log pCO$_2$ against log DOC for 4555 globally distributed lakes with DOC data available. Each point in the plot represents one individual lake. Circles, lakes with a single measurement. Triangles, mean values for lakes with multiple measurements. Solid line, linear regression for all data points in plot ($y = 2.67 + 0.414 \times x$; $R^2 = 0.26$; $p < 0.0001$). See color version of this figure in the HTML.

Sobek et al. (2005) GBC, 19, GB2003

Surface pCO$_2$ African comparison



Other pCO$_2$ data from Sobek et al. (2005) GBC, 19, GB2003

Comparison with lake Tanganyika

	salinity	pCO_2	TA	DIC	Ref.
Tanganyika	0.6	279	6541	5899	Graig (1974)
"main" Kivu	1.0	615	12970	11980	CAKI data
Kabuno	1.3	14210	16860	17240	CAKI data
atmosphere	-	380	-	-	-

Suggests a much larger contribution of geothermal inputs to surface water dynamics of inorganic C chemistry in lake Kivu than in lake Tanganyika related to geomorphology (depth, volume, river inputs)