Greenhouse gases in African inland waters

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Lab presentation

- Measurements of greenhouse gases in aquatic environments
- Inland waters, coastal waters, oceanic waters & marine cryosphere
- Versatile, compact and rugged equipment for harsh environments
- Carbon dioxide (CO$_2$) by infra-red & lazer analysers (Li-Cor & LGR)
- Continuous (surface) and discrete (profiles)
- Methane (CH$_4$) by gas chromatography (GC) & lazer analyser (LGR)
- Nitrous oxide (N$_2$O) concentration by GC
- N$_2$O isotopes by lazer spectrometry (LGR)
- Dimethylsulfide (DMS) by GC
1) CO₂ in European coastal waters (1996-2001)
CO₂ fluxes in European continental shelves (North Sea, English Channel, Celtic Sea, Iberian coast)

2) CO₂ in tropical estuaries (2001-2007)
CO₂ data in India, Vietnam, Kenya, and Ivory Coast.

3) CO₂, CH₄ & N₂O in freshwaters (2007-present)
African lakes & rivers
1 – Climate change & global cycles of CO$_2$ & CH$_4$
2 – Production of CO$_2$ et CH$_4$ in rivers
3 – CO$_2$ & CH$_4$ in African rivers
4 – Comparaison with Meuse
5 – A few words on African Lakes
1 – Climate change & global cycles of CO$_2$ & CH$_4$
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Introduction
Figure SPM.1 | (a) Observed global mean combined land and ocean surface temperature anomalies, from 1850 to 2012 from three data sets. Top panel: annual mean values. Bottom panel: decadal mean values including the estimate of uncertainty for one dataset (black). Anomalies are relative to the mean of 1961–1990. (b) Map of the observed surface temperature change from 1901 to 2012 derived from temperature trends determined by linear regression from one dataset (orange line in panel a). Trends have been calculated where data availability permits a robust estimate (i.e., only for grid boxes with greater than 70% complete records and more than 20% data availability in the first and last 10% of the time period). Other areas are white. Grid boxes where the trend is significant at the 10% level are indicated by a + sign. For a listing of the datasets and further technical details see the Technical Summary Supplementary Material. (Figures 2.19–2.21; Figure TS.2)
Introduction

Figure SPM.1 | (a) Observed global mean combined land and ocean surface temperature anomalies, from 1850 to 2012 from three data sets. Top panel: annual mean values. Bottom panel: decadal mean values including the estimate of uncertainty for one dataset (black). Anomalies are relative to the mean of 1961–1990. (b) Map of the observed surface temperature change from 1901 to 2012 derived from temperature trends determined by linear regression from one dataset (orange line in panel a). Trends have been calculated where data availability permits a robust estimate (i.e., only for grid boxes with greater than 70% complete records and more than 20% data availability in the first and last 10% of the time period). Other areas are white. Grid boxes where the trend is significant at the 10% level are indicated by a + sign. For a listing of the datasets and further technical details see the Technical Summary Supplementary Material. [Figures 2.19–2.21; Figure TS.2]
Introduction

Carbon dioxide (CO$_2$)
Global anthropogenic CO$_2$ fluxes in 2010 (PgC y$^{-1} = 10^{15}$ gC y$^{-1}$)

9.1±0.5 PgC y$^{-1}$

5.0±0.2 PgC y$^{-1}$
  50%

2.6±1.0 PgC y$^{-1}$
  26%

2.4±0.5 PgC y$^{-1}$
  24%

0.9±0.7 PgC y$^{-1}$

Calculated as the residual of all other flux components

Average of 5 models

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Global anthropogenic CO$_2$ fluxes in 2010 (PgC y$^{-1} = 10^{15}$ gC y$^{-1}$)

- 9.1 ± 0.5 PgC y$^{-1}$
- 0.9 ± 0.7 PgC y$^{-1}$
- 5.0 ± 0.2 PgC y$^{-1}$
- 2.6 ± 1.0 PgC y$^{-1}$
- 2.4 ± 0.5 PgC y$^{-1}$

9.1 + 0.9 + 5.0 = 2.6

26% Calculated as the residual of all other flux components

50% Average of 5 models

24%

National Reports
Cold water = absorption of $\text{CO}_2$ (Henry’s Law)
= dense (deep-water formation)
= long-term storage (coupled to $\text{CaCO}_3$ dissol.)
Why is the terrestrial biosphere a CO$_2$ sink?
= reforestation
The top four emitters in 2013 covered 58% of global emissions:
China (28%), United States (14%), EU28 (10%), India (7%)
Introduction

China’s per capita emissions have passed the EU28 and are 45% above the global average.
Introduction

Carbon dioxide (CO₂) emissions per capita (tonnes per year) vs GDP per capita (int.-$). The size of the bubbles represent population size.

Source: Penn World Table 9.0 (2016), CO2 emissions per capita by nation - CDIAC (2017)
Note: GDP (intl-§) presented as real GDP (2011) values
OurWorldInData.org/co2-and-other-greenhouse-gas-emissions/ • CC BY-SA
CO₂ emissions per capita vs GDP per capita (international-$), 2014
Carbon dioxide (CO₂) emissions per capita (tonnes per year) vs GDP per capita (int.-$). The size of the bubbles represent population size.

Source: Penn World Table 9.0 (2016), CO2 emissions per capita by nation - CDIAC (2017)
Note: GDP (intl-$) presented as real GDP (2011) values.
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**CO₂ emissions per capita vs. the share of people living in extreme poverty, 2013**

Average CO₂ emissions per capita are measured in tonnes per year. Extreme poverty is defined as living at a consumption (or income) level below 1.90 "international-$" per day. International $ are adjusted for price differences between countries and price changes over time (inflation).
Introduction

Methane (CH$_4$)
Introduction

Mauna Loa, Hawaii, United States (MLO)

(CH₄) Methane (nmol mol⁻¹)

Year

Data analysis by a climate-sceptic: «CH₄ is stable in time, IPCC is lying»
Introduction

Data analysis by a climate-scientist:
« I cannot explain it but it should contain knowledge »
**Introduction**

Mauna Loa, Hawaii, United States (MLO)

- **CH$_4$ life-time in atmosphere**: $\sim 10$ yrs
- **CO$_2$ life-time in atmosphere**: $\sim 100$ yrs
Sources and sinks of CH$_4$ in Tg CH$_4$ yr$^{-1}$

**Natural sources** = 337

- Natural wetlands (217)
- Freshwaters (40)
- Geological-land (36)
- Wild animals (15)
- Termites (11)
- Oceans (18)

**Anthropogenic sources** = 331

- Cattle (101)
- Landfills & waste (63)
- Rice (36)
- Fossil fuels (96)
- Biomass & biofuel burning (35)

**Atmospheric growth (2012)** = 12

**Sinks** = 632

Soils (28)
- Stratospheric Cl (25)
- Stratospheric loss (51)

Tropospheric OH$^-$ (528)

Kirschke et al. (2013) Nature Geoscience, 6, 813-823
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Introduction

POUR LA PRODUCTION D’UN KILO

- Emissions de gaz à effet de serre
  En kg équivalent CO₂
  - Bœuf : 41
  - Porc : 4900
  - Volaille : 4000

- Quantité d’eau nécessaire
  En litres
  - Bœuf : 15 500

- Terres nécessaires
  En m²
  - Bœuf : 60
  - Porc : 17
  - Volaille : 12

BLÉ : 1300 (0,28 m²)
SOJA : 2 750 (0,23 m²)
RIZ : 3 400 (0,41 m²)

Note : Ces chiffres proviennent de sources différentes et ont parfois été calculés avec des méthodes différentes. Sources : Life Cycle Assessment of Cultured Meat Production, l’Atlas de la viande, Unesco-IHE, FAO
Introduction

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Introduction

Sources and sinks of CH₄ in Tg CH₄ yr⁻¹

- Natural wetlands (217)
- Tropospheric OH⁻ (528)
- Stratospheric Cl (25)
- Stratospheric loss (51)
- Freshwaters (40) (130)
- Geological-land (36)
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Introduction

peatlands

aquatic macrophytes

flooded forest - swamps
Introduction

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Introduction

- CO₂ and CH₄ come from the degradation of organic matter
- Occurs in the river or in soils
- Transport by surface runoff and groundwater

Turbulence = f(wind, current)
Spatial patterns in CO$_2$ evasion from the global river network

Ronny Lauerwald$^{1,2,3}$, Goulven G. Laruelle$^{1,4}$, Jens Hartmann$^3$, Philippe Ciais$^5$, and Pierre A. G. Regnier$^1$

CO$_2$ emissions from rivers = 0.6 PgC yr$^{-1}$
Global anthropogenic CO₂ fluxes in 2010 (PgC y⁻¹ = 10^{15} gC y⁻¹)

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Statistical model of \( p\text{CO}_2 = f(\text{terrestrial net primary Production, human population density, air temperature, slope}) \)

Global maps of terrestrial net primary Production, human population density, air temperature, slope
Introduction

5 data!
Introduction

GHGs in lakes
Introduction

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Introduction

Congo river
Wetland = flooded forest (Tributary)
Wetland = floating macrophytes (Tributary)
Wetland = floating macrophytes (Congo mainstem)
Vossia cuspidata

Azolla pinnata

Salvinia auriculata

Eichhornia crassipes

« Hippo grass »

« water hyacinth »
Metamorphic courtesy of J. Hartmann

Siliciclastic and unconsolidated sed.
Kisangani

Kinshasa

1700 km

Kongo
Congo

Distance:
- Liege to Madrid, Espagne: 23 h 30 min, 1610 km

Countries passed:
- Cet itinéraire traverse le pays suivant : France.
Cruises & Methods

Long-term average water height at Kisangani (1912-2014)

3-19 December 2013

10-30 June 2014

164 stations
29 variables

> 23,000 continuous measurements
pCO$_2$, cond, temp, pH, O$_2$, TSM, cDOM
Cruises & Methods
Results

Conductivity (μS cm⁻¹)

- High W (Dec. 2013)
- Falling W (June 2014)

pH

Cuvette Centrale (Wetland)  Black-water tributaries

Longitude (°E)

← Dowstream  Upstream →
Results

$pCO_2$ (ppm) vs Longitude ($^\circ$E)

- High W (Dec. 2013)
- Falling W (June 2014)

$%O_2$ (%) vs Longitude ($^\circ$E)

- Cuvette Centrale (Wetland)
- Black-water tributaries
Results

- « Cuvette Centrale » (Wetland)
- Savanna
Results

CH$_4$ (nmol L$^{-1}$)

- « Cuvette Centrale » (Wetland)
- Savannah

Mainstem High W
Tributaries High W
Mainstem Falling W
Tributaries Falling W
Results

All streams/rivers vs catchment characteristics

- %O₂ (%): $r^2 = 0.95$
- pCO₂ (ppm): $r^2 = 0.90$
- N₂O (nmol L⁻¹): $r^2 = 0.67$
- CH₄ (nmol L⁻¹): $r^2 = 0.72$

Streams/rivers vs catchment characteristics
Results

Congo & other African rivers
Results
Results

- **PCO**₂ (ppm)
- **%O₂**
- **CH₄** (nmol L⁻¹)
- **N₂O** (nmol L⁻¹)
- **DOC** (mg L⁻¹)

**Springs**:
- Congo
- Zambezi
- Tana
- AGS
- Rianila
- Betsiboka
Results

- CH$_4$ (nmol L$^{-1}$) with $r^2 = 0.94$
- pCO$_2$ (ppm) with $r^2 = 0.99$
- %O$_2$ (%) with $r^2 = 0.96$

Graphs showing the relationship between wetland fraction of catchment and gas concentrations.
Results

Steeper → short residence time → smaller flood areas → high exchange + air

- Congo
- Zambezi
- AGS
- Betisiboka
- Rianila
- Nyong
Results

**Steeper**
- short residence time
- smaller flood areas
- high exchange + air

Graph 1: % dense forest cover vs. $pCO_2$ (ppm)

Graph 2: Catchment slope (°) vs. $pCO_2$ (ppm)
Results

African rivers/streams
$\text{CO}_2 + \text{CH}_4 = 0.4 \text{ PgC yr}^{-1} (\text{CO}_2 \text{ equivalents})$

African rivers/streams + Cuvette Centrale Congolaise
$\text{CO}_2 + \text{CH}_4 = 1.0 \text{ PgC yr}^{-1} (\text{CO}_2 \text{ equivalents})$
Global anthropogenic CO$_2$ fluxes in 2010 (PgC y$^{-1}$ = 10$^{15}$ gC y$^{-1}$)

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Results
Results

**CH₄ (nmol L⁻¹)**

- **Forested**
  - 0 nmol L⁻¹
- **Agricultural**
  - 1,000 nmol L⁻¹

**pCO₂ (ppm)**

- **Forested**
  - 4,000 ppm
- **Agricultural**
  - 6,000 ppm
Results

The graph shows the concentration of CH₄ (nmol L⁻¹) on the y-axis and % O₂ (%) on the x-axis. The data points represent measurements from four different locations: Geer, Meuse, Congo, and Zambezi. Each location is indicated by a different symbol: Geer (diamond), Meuse (circle), Congo (triangle), and Zambezi (asterisk). The data points are scattered across the graph, suggesting a range of CH₄ concentrations and % O₂ values for each location.
Results
Results

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Results

On going research in Lakes Edward, George, Victoria, Tanganyika