Greenhouse gas emissions from African lakes

Alberto Borges

University of Liège (Belgium)
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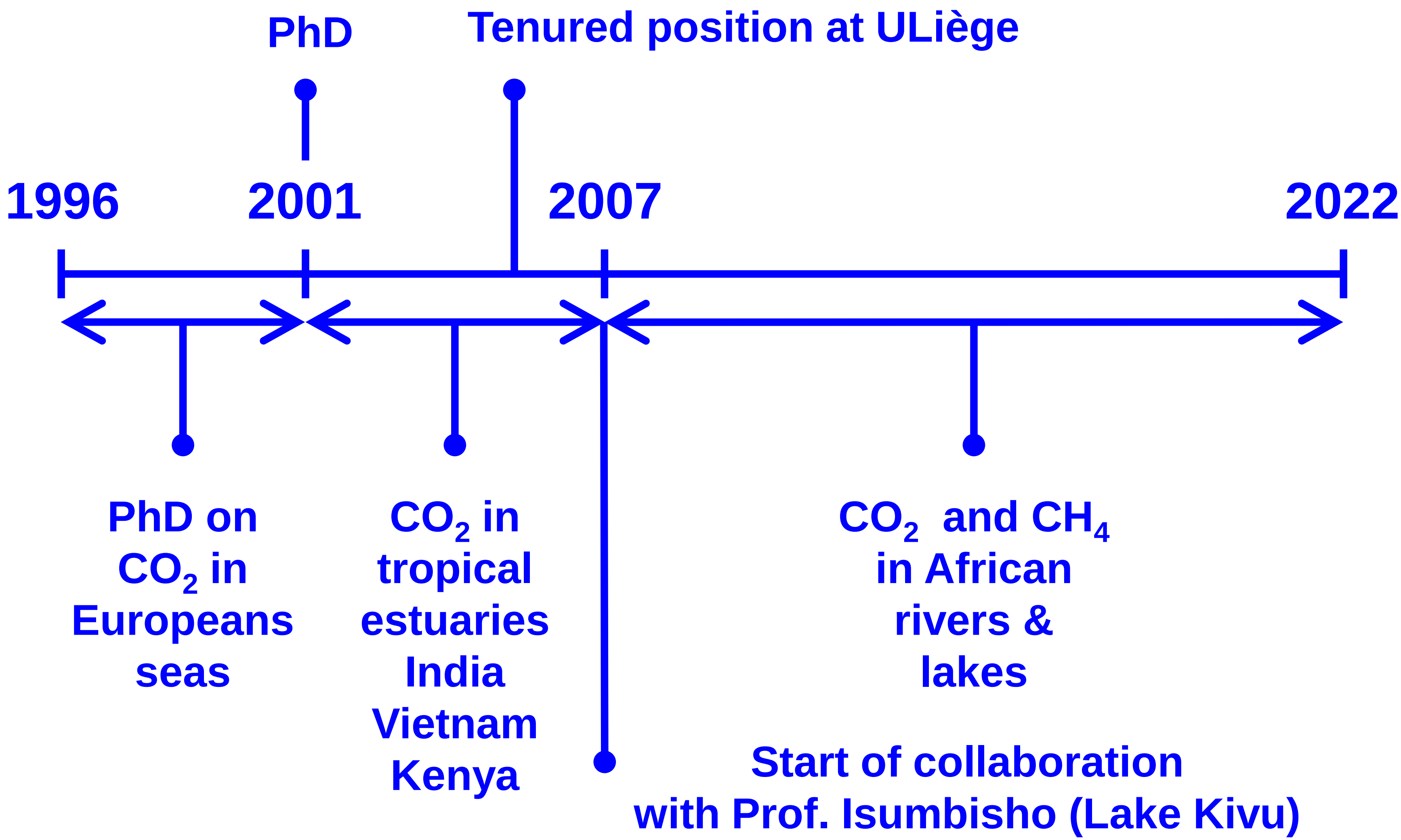
Outline of presentation

- Presentation of myself and my institution
- Introduction
  - Climate change
  - Global CO_2 cycle
  - Global CH_4 cycle
  - CO_2 and CH_4 in lakes
- CO_2 and CH_4 emissions from African lakes

Presentation

Presentation



Presentation

University of Liège

- 10 Faculties
- 1 School of Management
- ±25,000 students
- ±40 Bachelor and ±200 Master degrees
- ±2,100 PhD-candidates
- ±3,500 professors and researchers

Presentation

LIÈGE université
Chemical Oceanography

- CO_2, CH_4 and N_2O concentrations & isotopes

Presentation

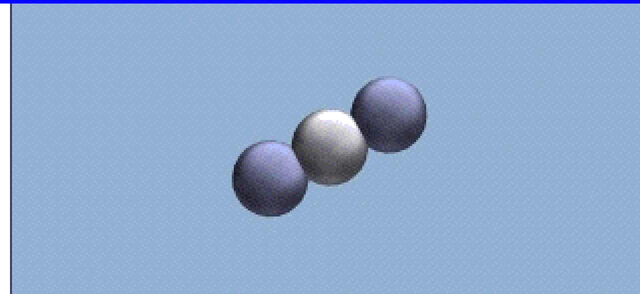
LIÈGE université
Chemical Oceanography

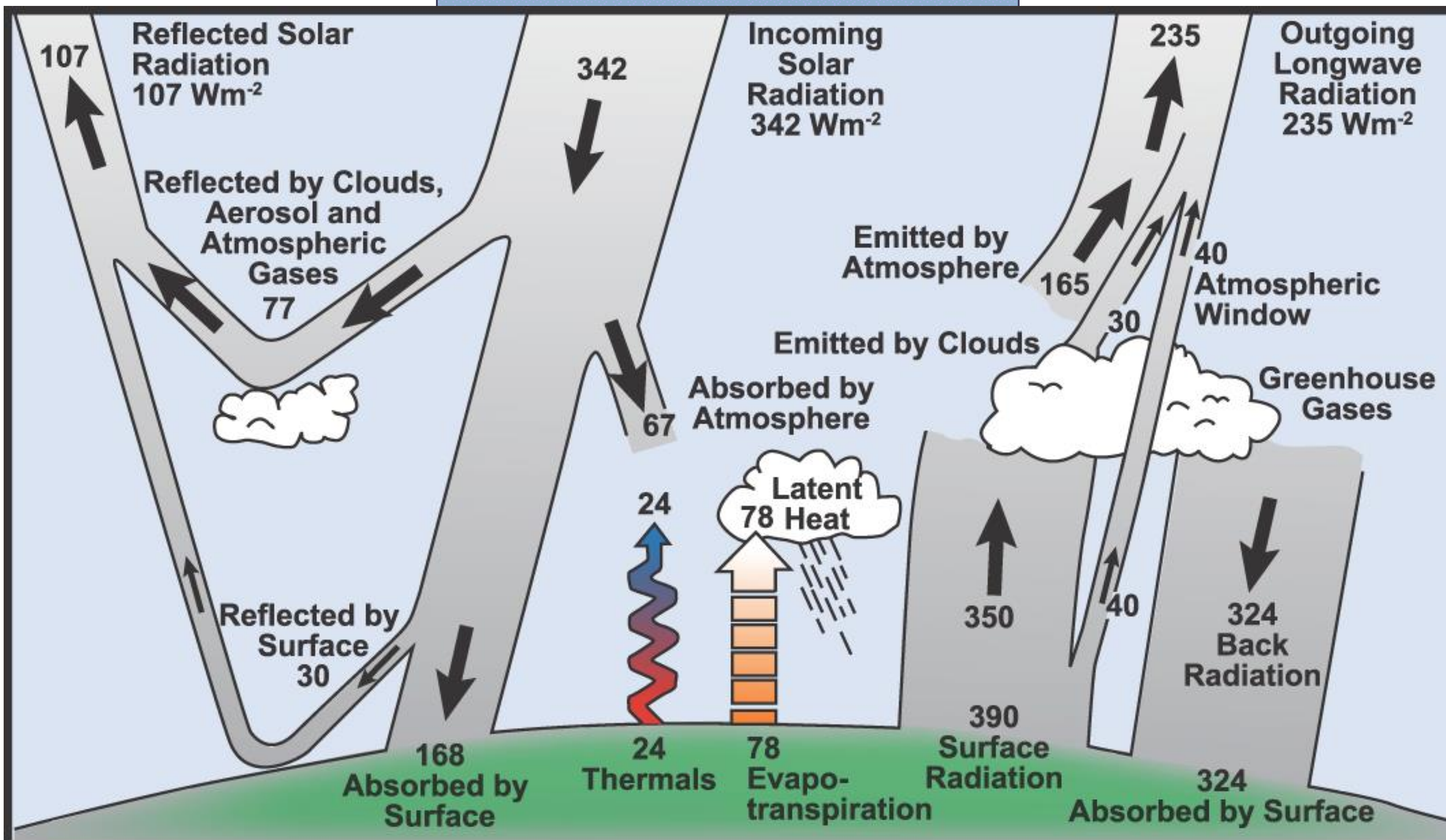
- CO_2, CH_4 and N_2O concentrations & isotopes
- Organic carbon in collaboration with Prof. Steven Bouillon (KULeuven)

DEPARTMENT OF EARTH AND ENVIRONMENTAL SCIENCES
KU Leuven - BELGIUM

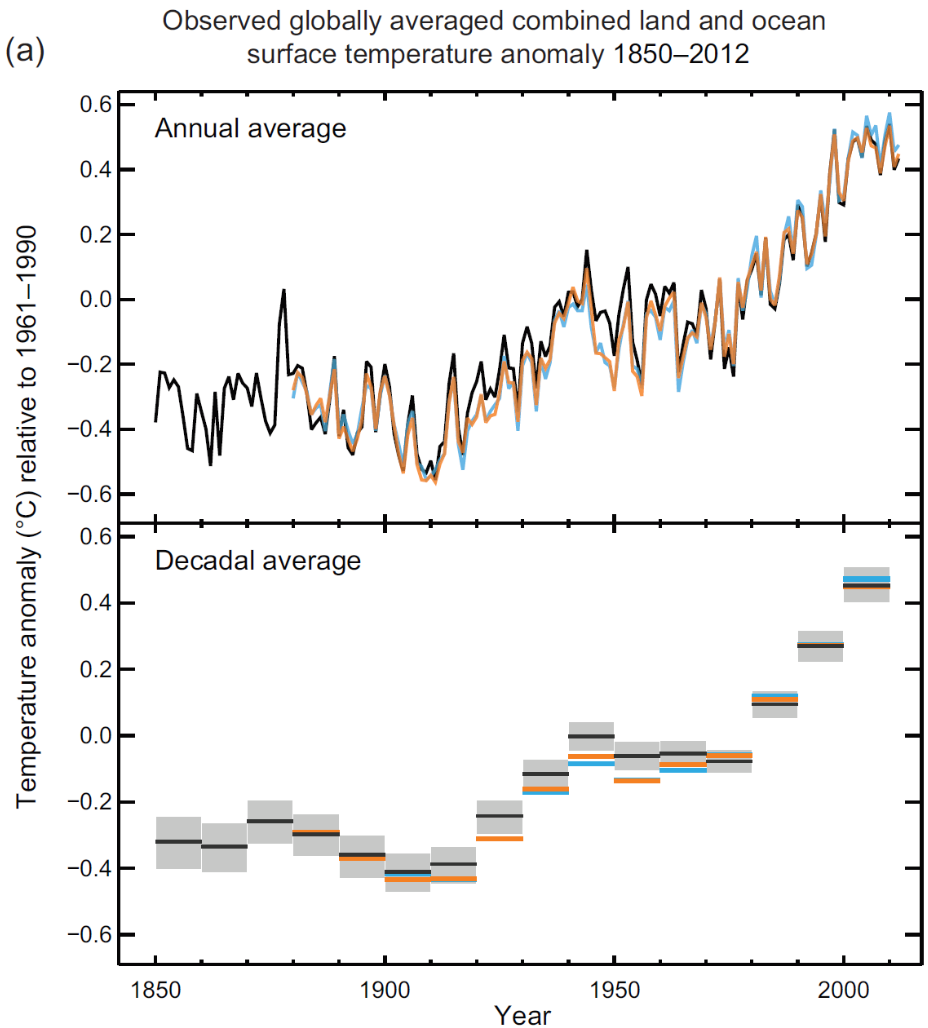
Introduction
Climate change

Introduction





Introduction



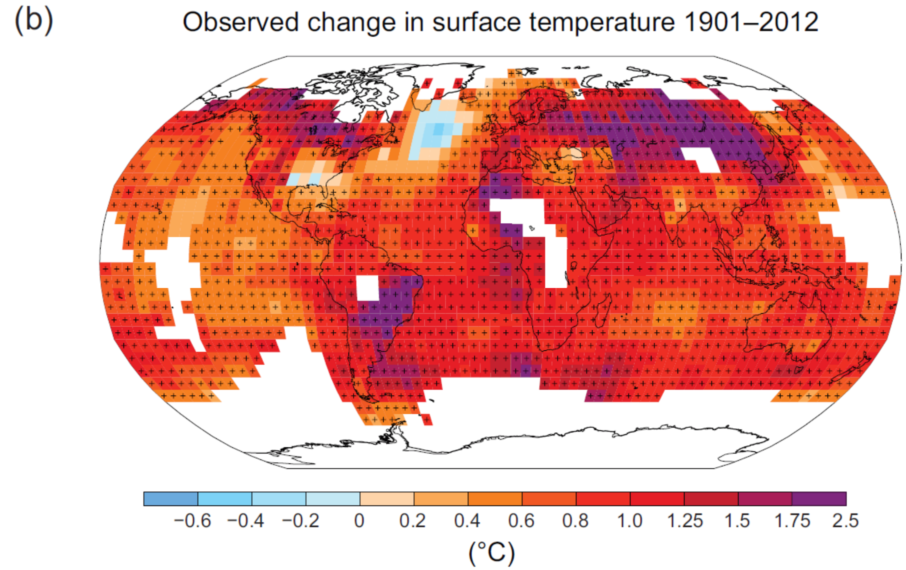
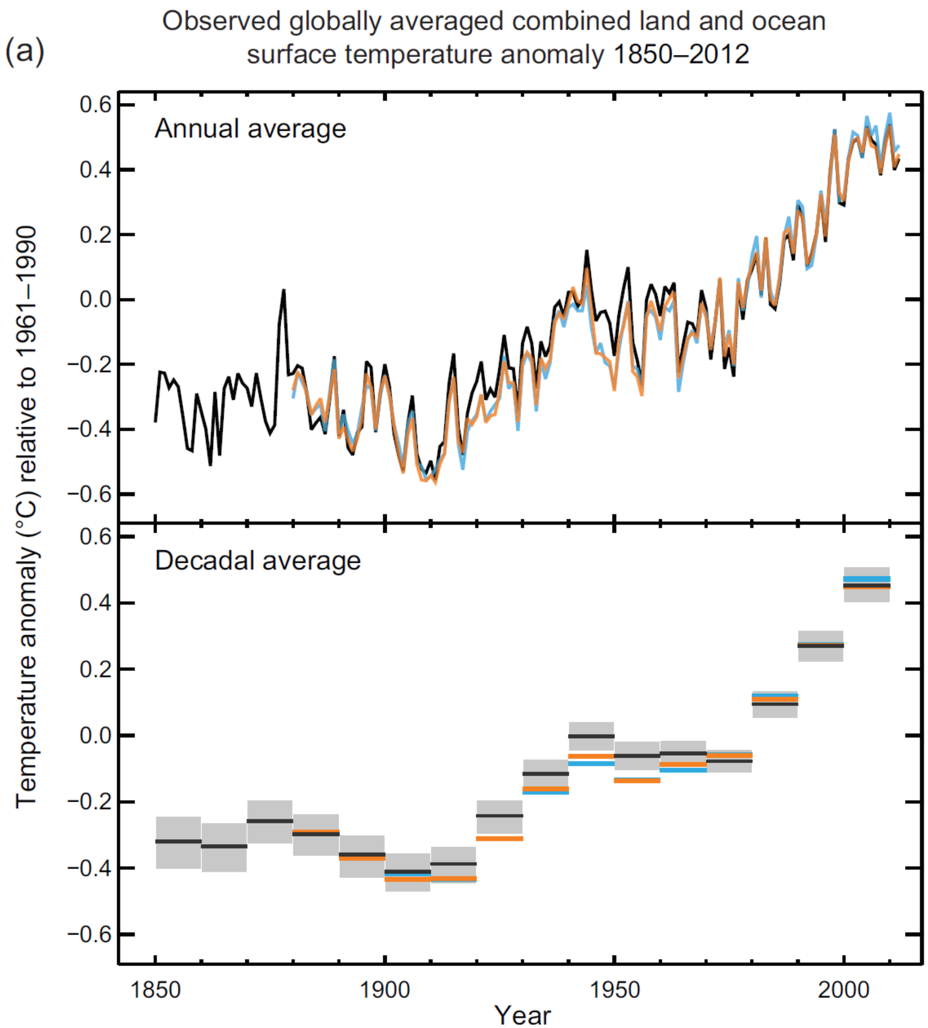
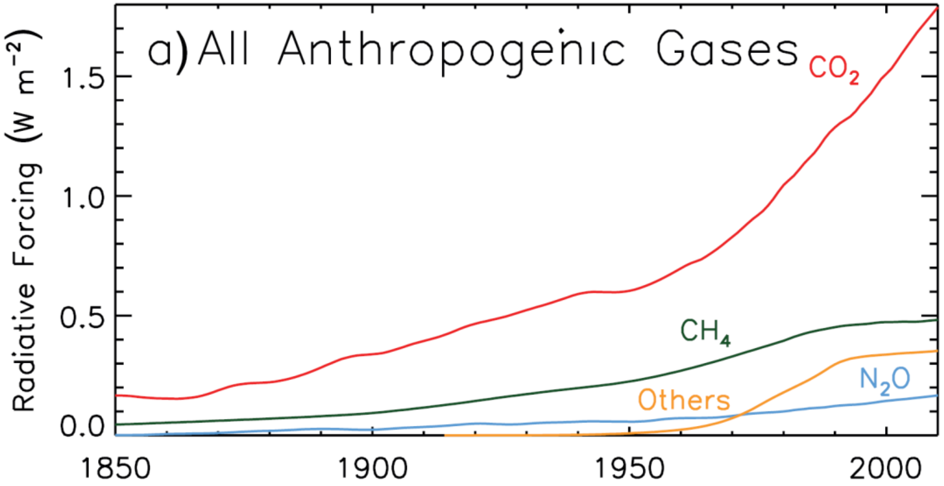


Figure SPM.1 | (a) Observed global mean combined land and ocean surface temperature anomalies, from 1850 to 2012 from three data sets. Top panel: annual mean values. Bottom panel: decadal mean values including the estimate of uncertainty for one dataset (black). Anomalies are relative to the mean of 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





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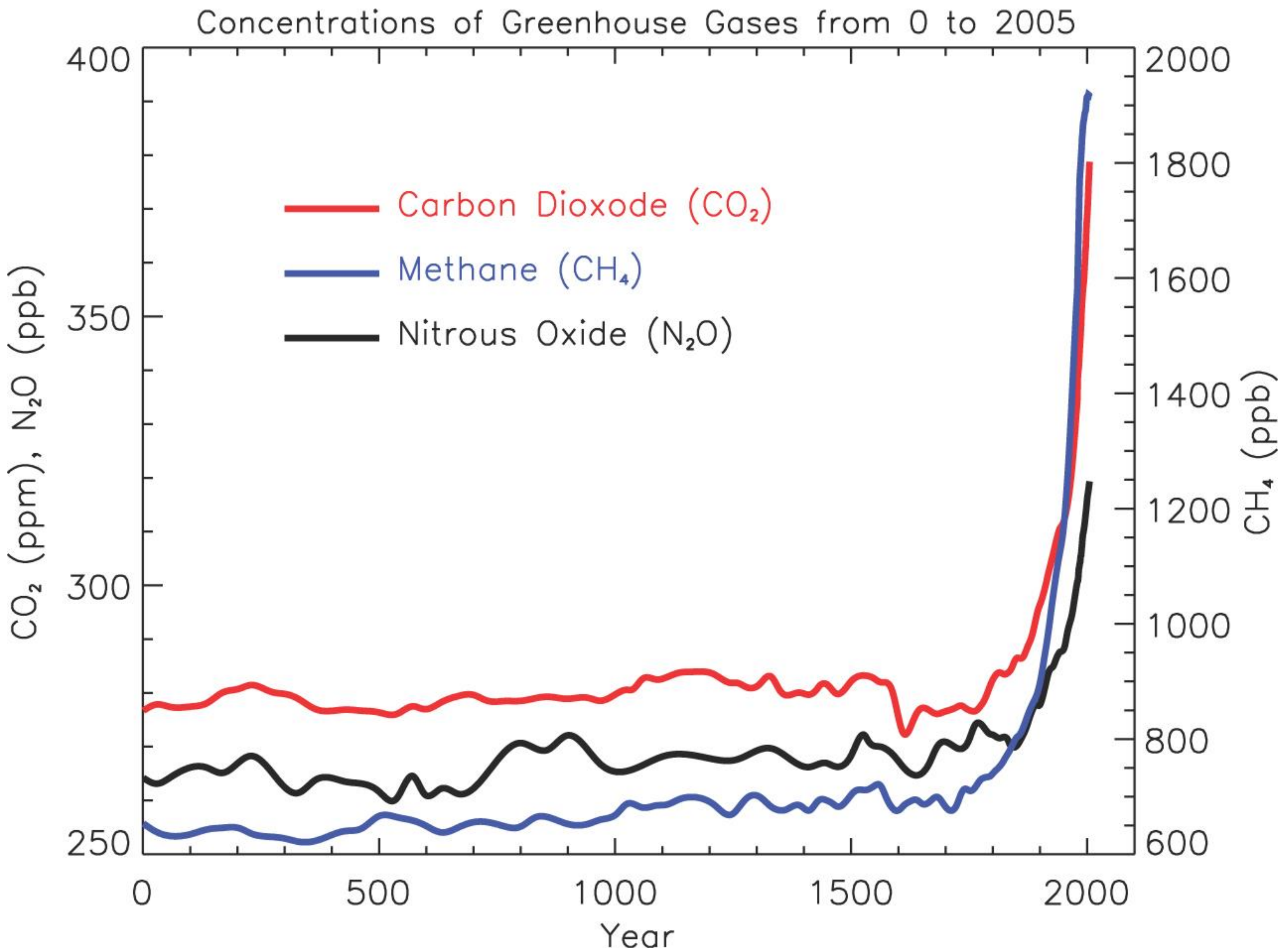
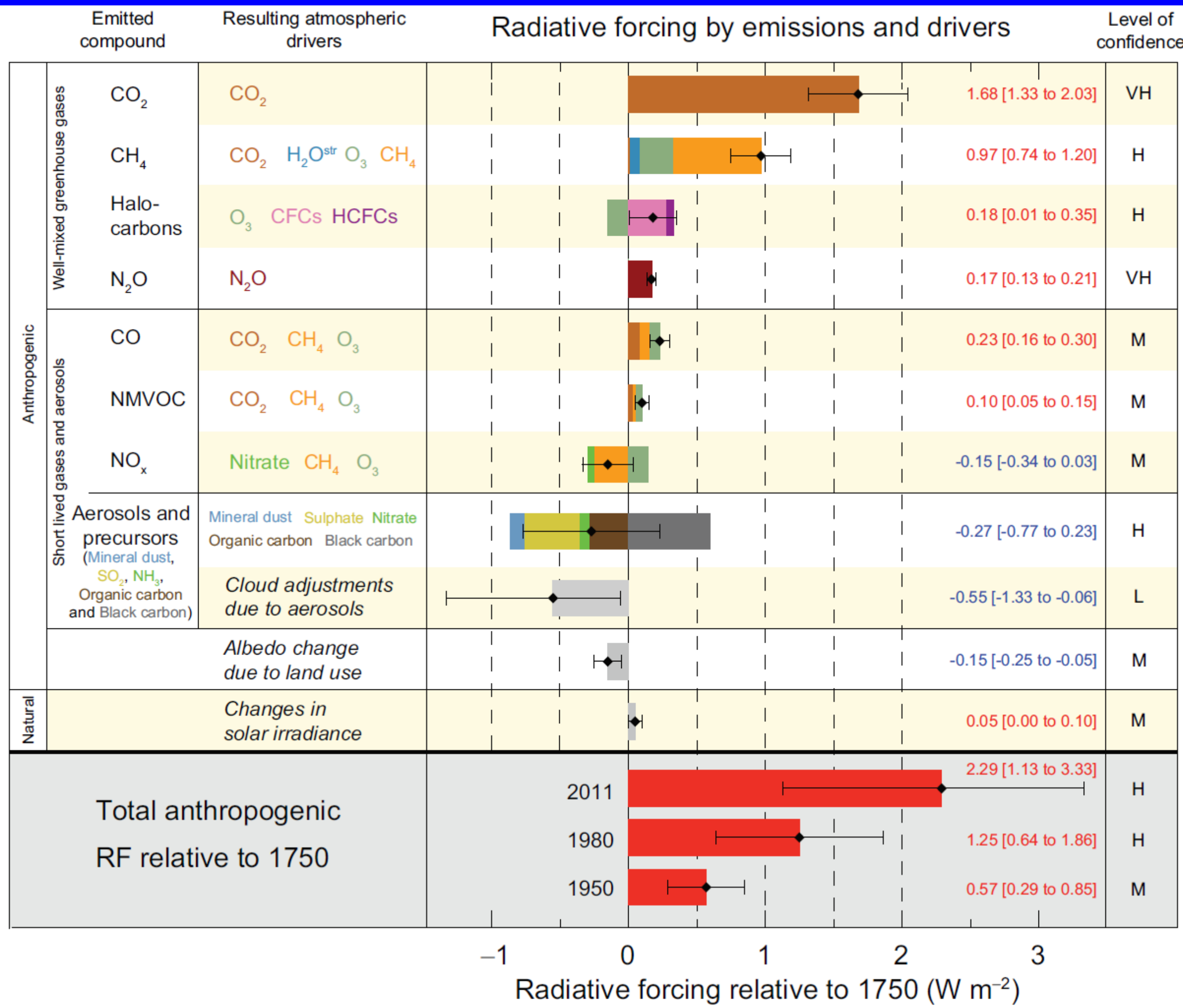


Introduction



CO_2 = 56%

CH_4 = 32%

HaloC = 6%

N_2O = 6%

Figure SPM.5 | Radiative forcing estimates in 2011 relative to 1750 and aggregated uncertainties for the main drivers of climate change. Values are global average radiative forcing (RF[14]), partitioned according to the emitted compounds or processes that result in a combination of drivers. The best estimates of the net radiative forcing are shown as black diamonds with corresponding uncertainty intervals; the numerical values are provided on the right of the figure, together with the confidence level in the net forcing (VH – *very high*, H – *high*, M – *medium*, L – *low*, VL – *very low*). Albedo forcing due to black carbon on snow and ice is included in the black carbon aerosol bar. Small forcings due to contrails (0.05 W m^{-2}, including contrail induced cirrus), and HFCs, PFCs and SF_6 (total 0.03 W m^{-2}) are not shown. Concentration-based RFs for gases can be obtained by summing the like-coloured bars. Volcanic forcing is not included as its episodic nature makes is difficult to compare to other forcing mechanisms. Total anthropogenic radiative forcing is provided for three different years relative to 1750. For further technical details, including uncertainty ranges associated with individual components and processes, see the Technical Summary Supplementary Material. {8.5; Figures 8.14–8.18; Figures TS.6 and TS.7}

Introduction
Global CO_2 cycle

Introduction

Global anthropogenic CO_2 fluxes in 2010 ($PgC\ y^{-1} = 10^{15}\ gC\ y^{-1}$)

$9.1 \pm 0.5\ PgC\ y^{-1}$

+

$0.9 \pm 0.7\ PgC\ y^{-1}$

$5.0 \pm 0.2\ PgC\ y^{-1}$

50%

$2.6 \pm 1.0\ PgC\ y^{-1}$

26%

Calculated as the residual of all other flux components

24%

$2.4 \pm 0.5\ PgC\ y^{-1}$

Average of 5 models

www.globalcarbonproject.org/

Introduction

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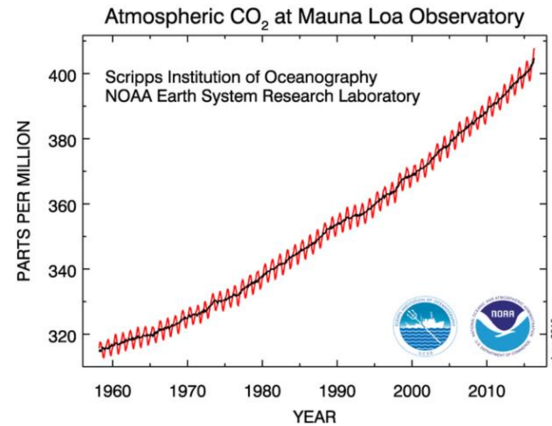

$9.1 \pm 0.5\ PgC\ y^{-1}$

United Nations
Framework Convention on
Climate Change

National Reports

$+$

$0.9 \pm 0.7\ PgC\ y^{-1}$

Food and Agriculture
Organization of the
United Nations

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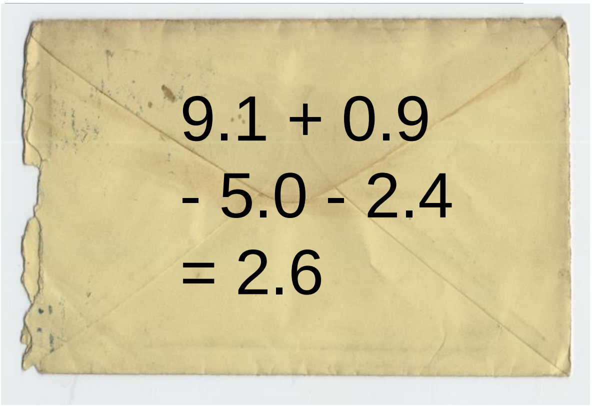

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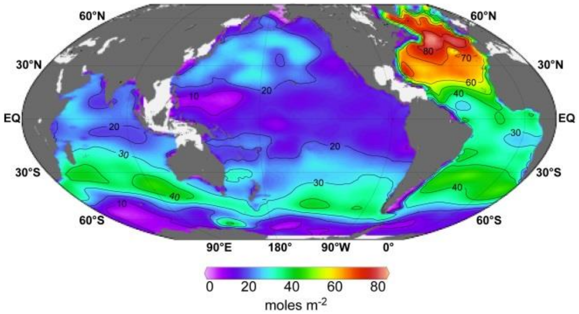

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Introduction

What about rivers ?

Introduction

River CO_2 global emission
1.8 PgC yr^{-1} (Raymond et al. 2013)

Global carbon dioxide emissions from inland waters

Peter A. Raymond[1], Jens Hartmann[2]*, Ronny Lauerwald[2,3]*, Sebastian Sobek[4]*, Cory McDonald[5], Mark Hoover[1], David Butman[1,6], Robert Striegl[6], Emilio Mayorga[7], Christoph Humborg[8], Pirkko Kortelainen[9], Hans Dürr[10], Michel Meybeck[11], Philippe Ciais[12] & Peter Guth[13]

Introduction

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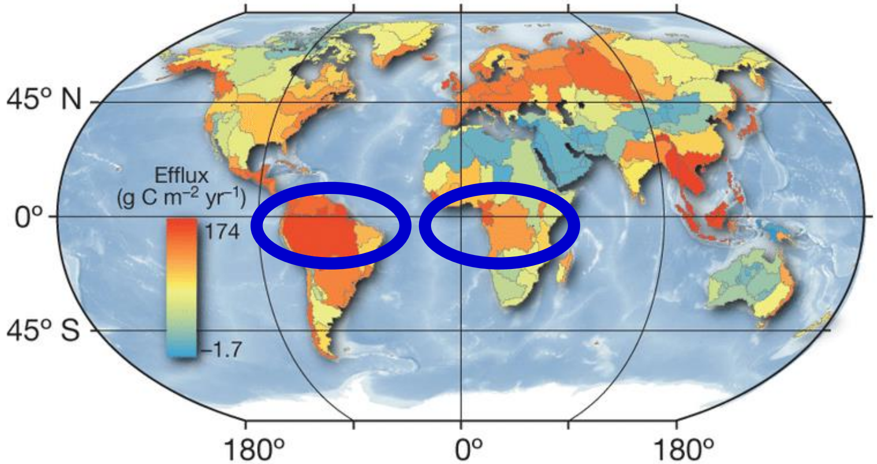
Spatial patterns in CO_2 evasion from the global river network

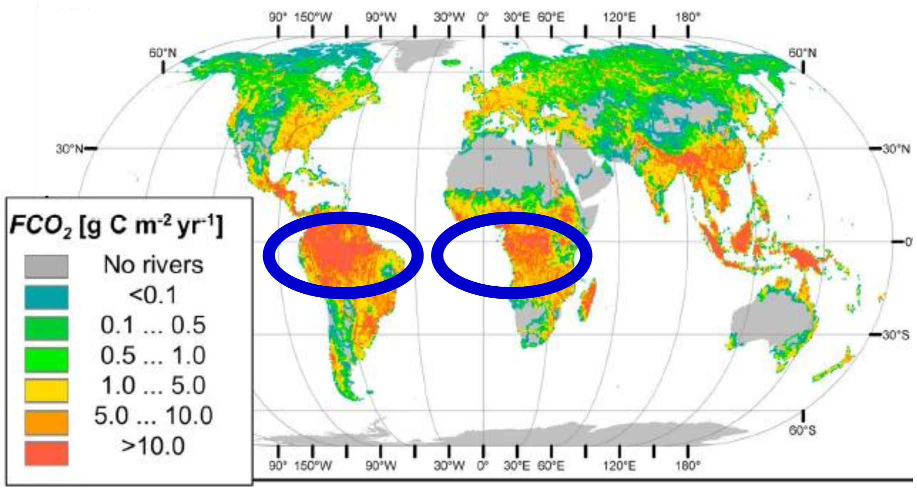
Ronny Lauerwald[1,2,3], Goulven G. Laruelle[1,4], Jens Hartmann[3], Philippe Ciais[5], and Pierre A. G. Regnier[1]

Introduction

Raymond et al. (2013)



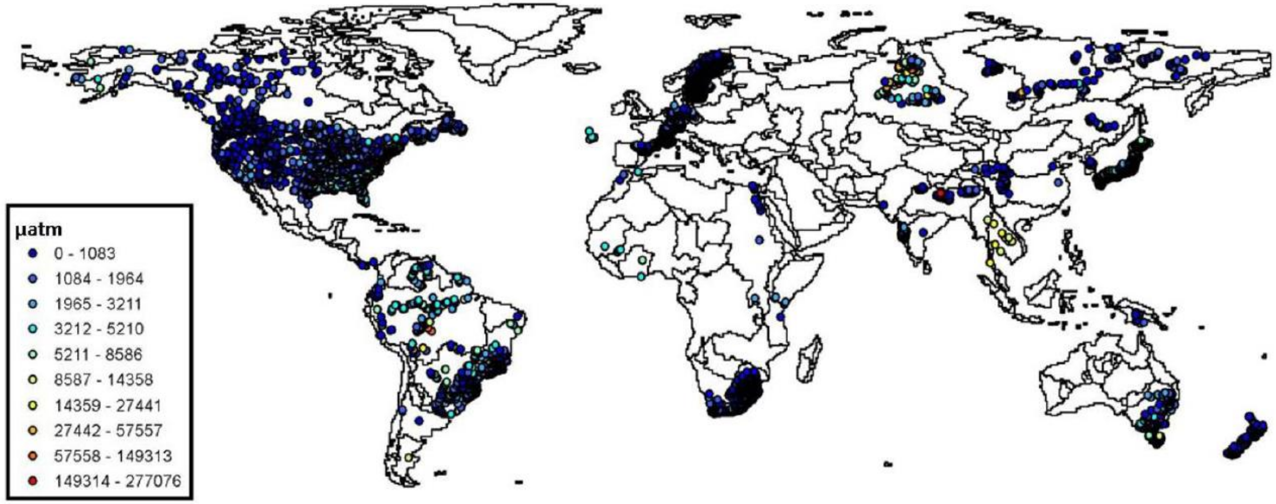
Lauerwald et al. (2015)



High CO_2 emissions in the tropics (Amazon & Congo)

Introduction

Raymond et al. (2013)



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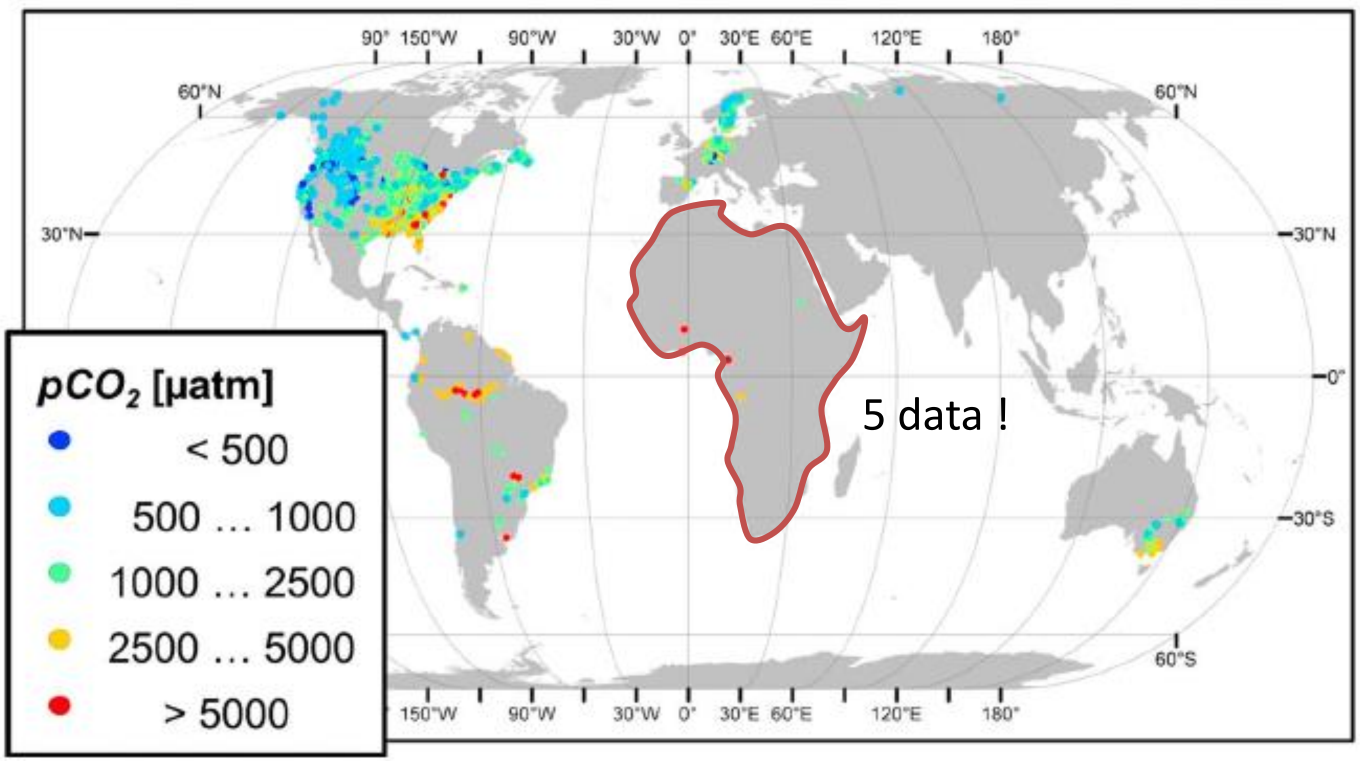

Introduction

nature geoscience

ARTICLES

PUBLISHED ONLINE: 20 JULY 2015 | DOI: 10.1038/NGEO2486

Globally significant greenhouse-gas emissions from African inland waters

Alberto V. Borges[1*], François Darchambeau[1], Cristian R. Teodoru[2], Trent R. Marwick[2], Fredrick Tamooh[2,3], Naomi Geeraert[2], Fredrick O. Omengo[2], Frédéric Guérin[4], Thibault Lambert[1], Cédric Morana[2], Eric Okuku[2,5] and Steven Bouillon[2]

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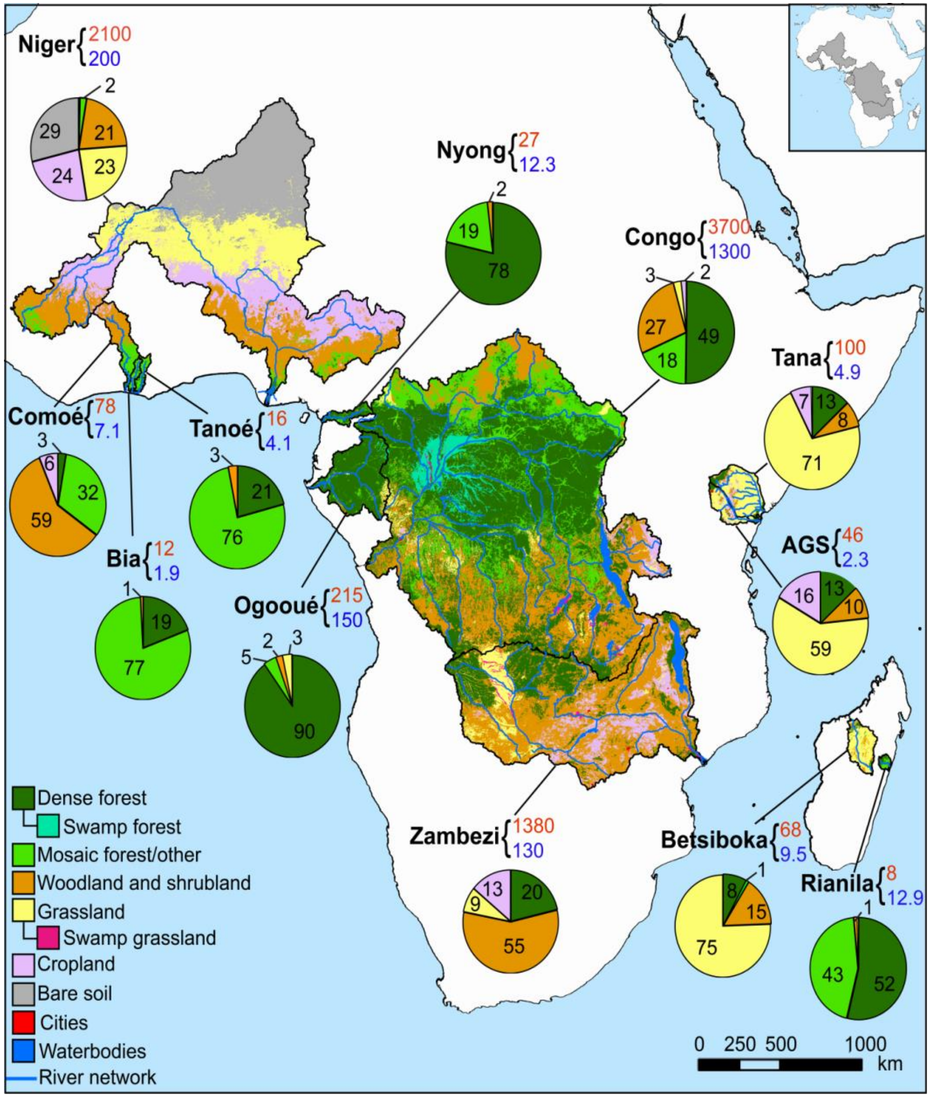

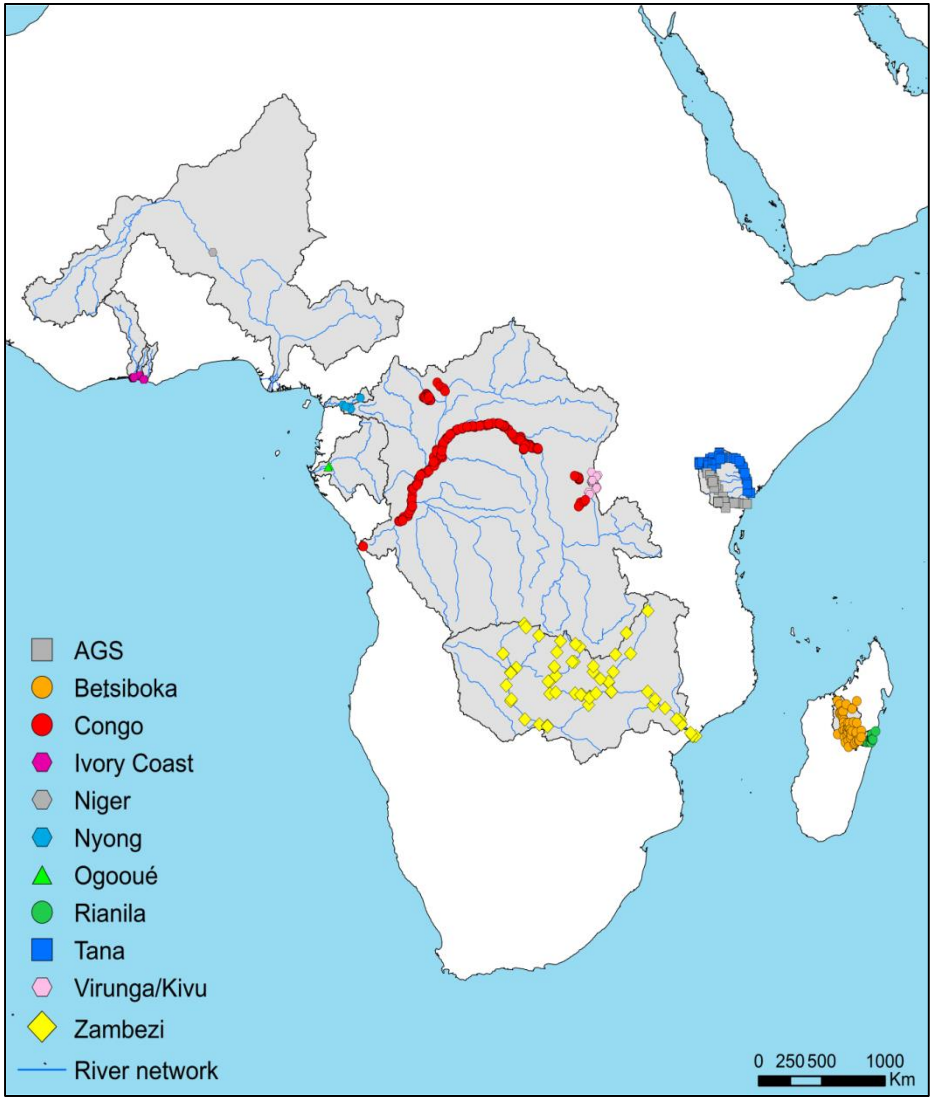

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Carbon dioxide emissions to the atmosphere from inland waters—streams, rivers, lakes and reservoirs—are nearly equivalent to ocean and land sinks globally. Inland waters can be an important source of methane and nitrous oxide emissions as well, but emissions are poorly quantified, especially in Africa. Here we report dissolved carbon dioxide, methane and nitrous oxide concentrations from 12 rivers in sub-Saharan Africa, including seasonally resolved sampling at 39 sites, acquired between 2006 and 2014. Fluxes were calculated from published gas transfer velocities, and upscaled to the area of all sub-Saharan African rivers using available spatial data sets. Carbon dioxide-equivalent emissions from river channels alone were about 0.4 Pg carbon per year, equivalent to two-thirds of the overall net carbon land sink previously reported for Africa. Including emissions from wetlands of the Congo river increases the total carbon dioxide-equivalent greenhouse-gas emissions to about 0.9 Pg carbon per year, equivalent to about one quarter of the global ocean and terrestrial combined carbon sink. Riverine carbon dioxide and methane emissions increase with wetland extent and upland biomass. We therefore suggest that future changes in wetland and upland cover could strongly affect greenhouse-gas emissions from African inland waters.

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Introduction

What about lakes ?

Introduction

SCIENCE • VOL. 265 • 9 SEPTEMBER 1994

Carbon Dioxide Supersaturation in the Surface Waters of Lakes

Jonathan J. Cole, Nina F. Caraco, George W. Kling, Timothy K. Kratz

Data on the partial pressure of carbon dioxide (CO_2) in the surface waters from a large number of lakes (1835) with a worldwide distribution show that only a small proportion of the 4665 samples analyzed (less than 10 percent) were within ±20 percent of equilibrium with the atmosphere and that most samples (87 percent) were supersaturated. The

Introduction

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Introduction

Limnol. Oceanogr., 33(1), 1988, 27–40
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Comparative transparency, depth of mixing, and stability of stratification in lakes of Cameroon, West Africa[1]

George W. Kling[2]

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Introduction

The 1986 Lake Nyos Gas Disaster in Cameroon, West Africa

George W. Kling, Michael A. Clark, Harry R. Compton, Joseph D. Devin
William C. Evans, Alan M. Humphrey, Edward J. Koenigsberg,
John P. Lockwood, Michele L. Tuttle, Glen N. Wagner

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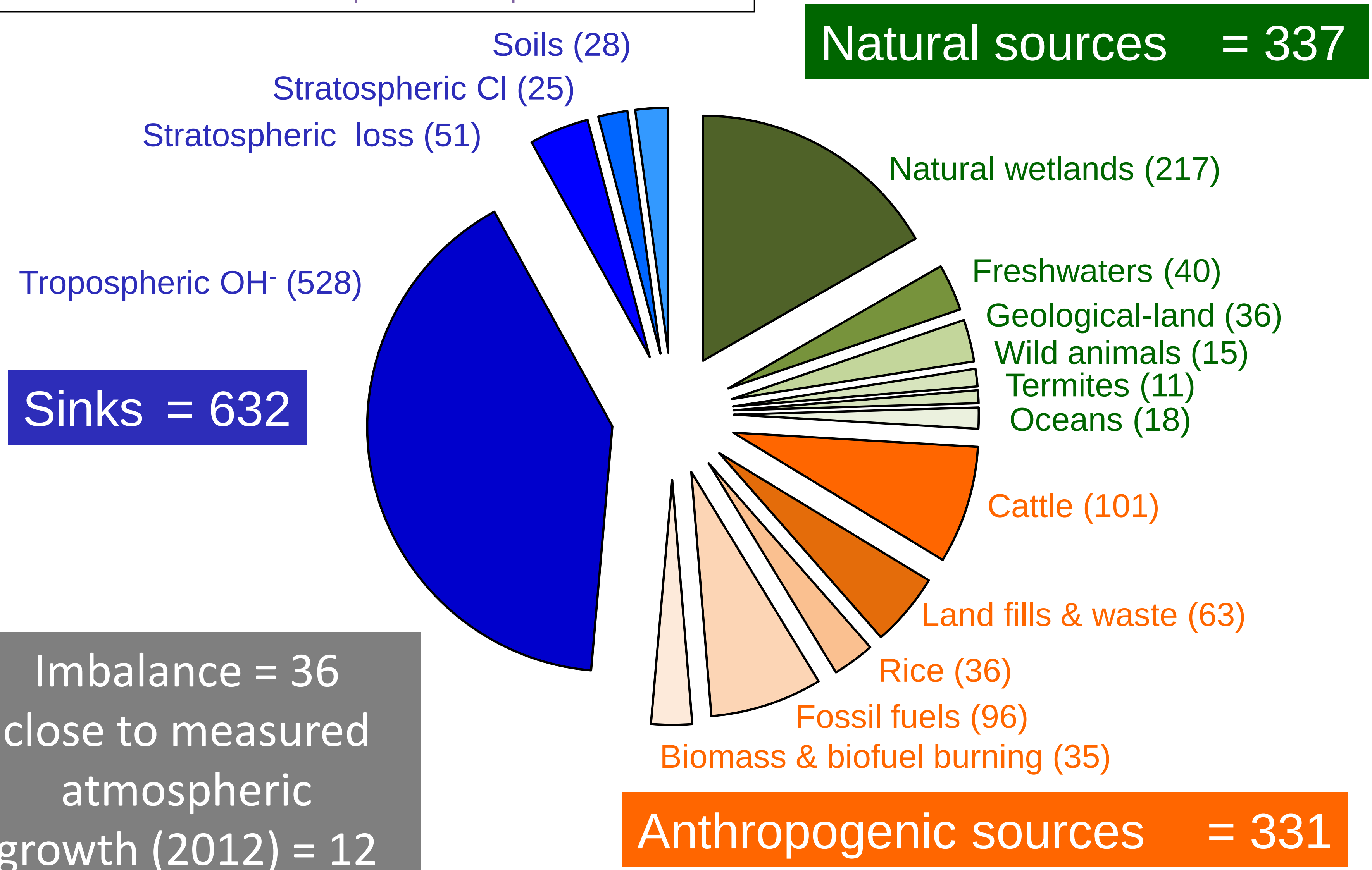
The sudden, catastrophic release of gas from Lake Nyos on 21 August 1986 caused the deaths of at least 1700 people in the northwest area of Cameroon, West Africa. Chemical, isotopic, geologic, and medical evidence support the hypotheses that (i) the bulk of gas released was carbon dioxide that had been stored in the lake's hypolimnion, (ii) the victims exposed to the gas cloud died of carbon dioxide asphyxiation, (iii) the carbon dioxide was derived from magmatic sources, and (iv) there was no significant, direct volcanic activity involved. The limnological nature of the gas release suggests that hazardous lakes may be identified and monitored and that the danger of future incidents can be reduced.

Introduction

Global CH_4 cycle

Introduction

Sources and sinks of CH_4 in Tg CH_4 yr^{-1}

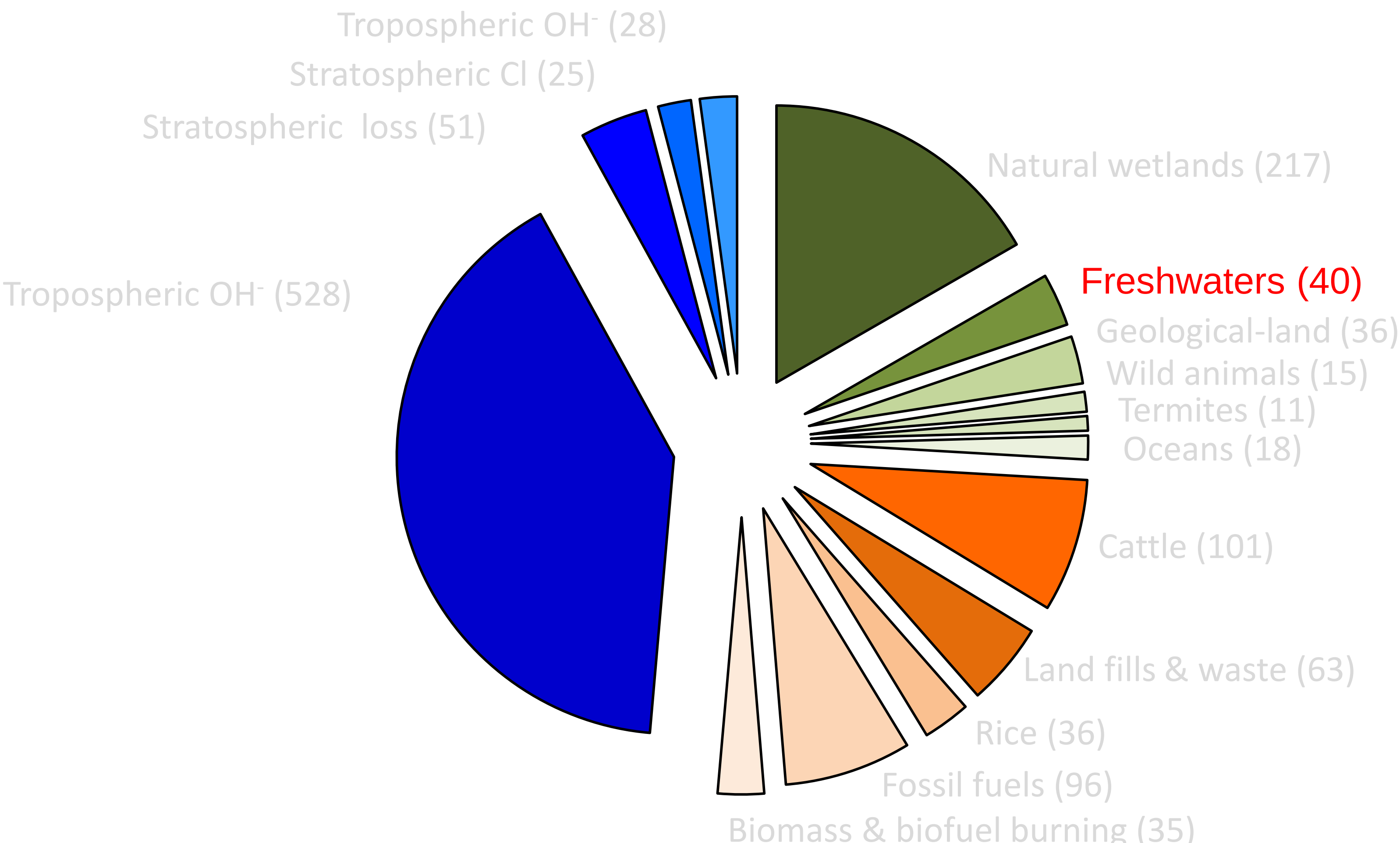


Imbalance = 36 close to measured atmospheric growth (2012) = 12

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

Introduction

Sources and sinks of CH_4 in Tg CH_4 yr^{-1}



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

Introduction

Freshwater Methane Emissions Offset the Continental Carbon Sink

David Bastviken,[1*] Lars J. Tranvik,[2] John A. Downing,[3] Patrick M. Crill,[4] Alex Enrich-Prast[5]

Latitude	Fluxes												Area (km^2)
	Total open water			Ebullition			Diffusive			Stored			
	Emiss.	*n*	CV	Emiss.	*n*	CV	Emiss.	*n*	CV	Emiss.	*n*	CV	
						Lakes							
>66°	6.8	17	72	6.4	17	74	0.7	60	37				288,318
>54°–66°	6.6	5	155	9.1	9	60	1.1	271	185	0.1	217	2649	1,533,084
25°–54°	31.6	15	127	15.8	15	177	4.8	33	277	3.7	36	125	1,330,264
<24°	26.6	29	51	22.2	28	54	3.1	29	97	21.3	1		585,536*
						Reservoirs							
>66°	0.2†												35,289
>54°–66°	1.0	24	176	1.8	2	140	0.2	4	93				161,352
25°–54°	0.7‡												116,922
<24°	18.1	11	87										186,437
						Rivers	Total = 1.5 $TgCH_4\ yr^{-1}$						
>66°	0.1	1											38,895
>54°–66°	0.2†												80,009
25°–54°	0.3	20	302										61,867
<24°	0.9‡												176,856
Sum open water	93.1	116		55.3	71		9.9	397		25.1	254		
Plant flux	10.2												
Sum all	103.3												

*Likely underestimated. For comparison, the mean flooded areas for the major South American savanna wetlands and the lowland Amazon (below 500 m above sea level) are 115,620 km^2 and 750,000 km^2, respectively (*14*). †Estimated assuming similar emissions per area unit at latitudes >54°. ‡Estimated assuming similar emissions per area unit at latitudes from 0° to 54°.

Introduction

The ecology of methane in streams and rivers: patterns, controls, and global significance

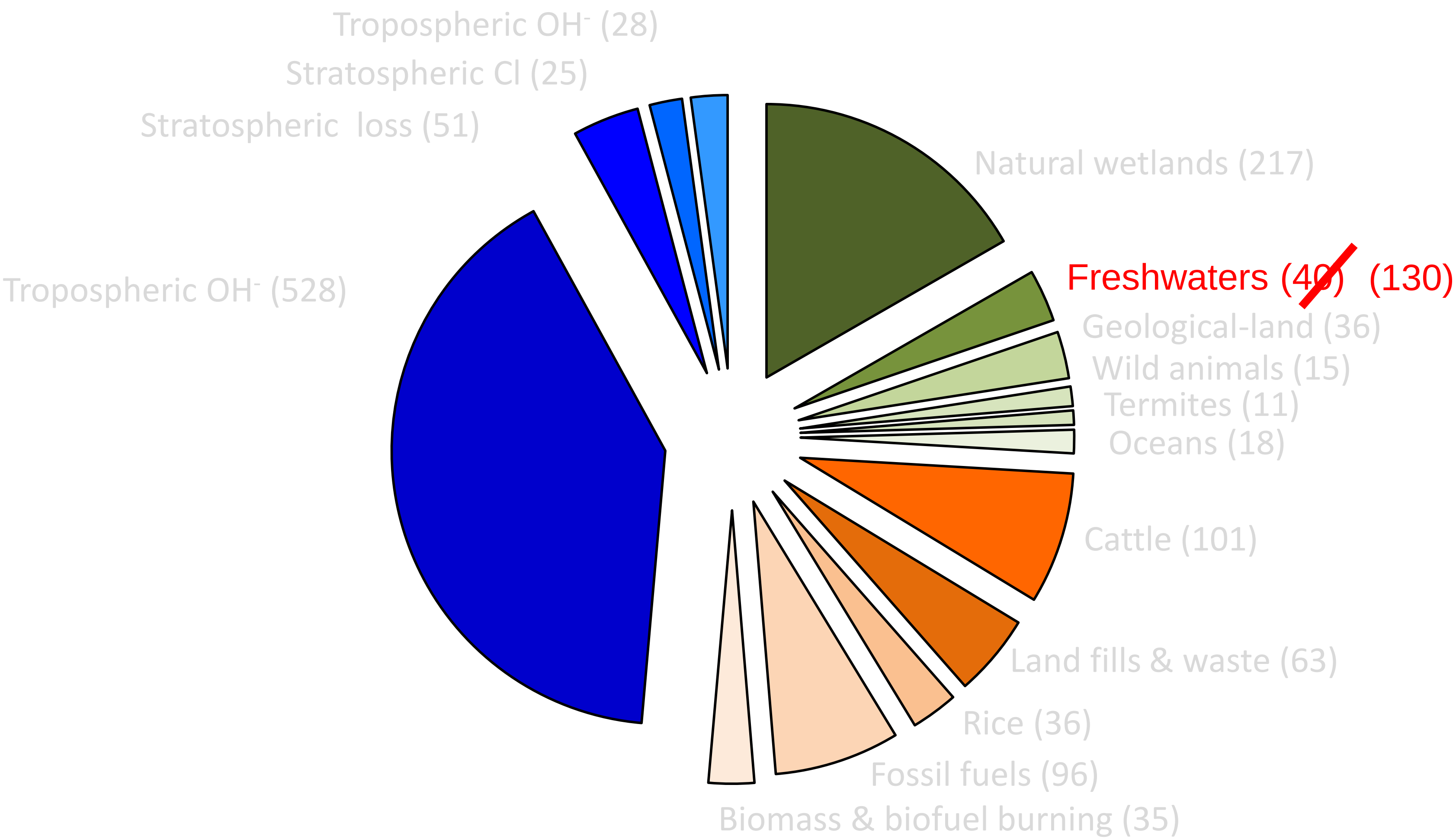
Emily H. Stanley,[1,4] Nora J. Casson,[1,3] Samuel T. Christel,[1] John T. Crawford,[2] Luke C. Loken,[1] and Samantha K. Oliver[1]

[1]*Center for Limnology, University of Wisconsin, 680 North Park Street, Madison, Wisconsin 53706 USA*
[2]*U.S. Geological Survey, 3215 Marine Street Suite E127, Boulder, Colorado 80303 USA*

Abstract. Streams and rivers can substantially modify organic carbon (OC) inputs from terrestrial landscapes, and much of this processing is the result of microbial respiration. While carbon dioxide (CO_2) is the major end-product of ecosystem respiration, methane (CH_4) is also present in many fluvial environments even though methanogenesis typically requires anoxic conditions that may be scarce in these systems. Given recent recognition of the pervasiveness of this greenhouse gas in streams and rivers, we synthesized existing research and data to identify patterns and drivers of CH_4, knowledge gaps, and research opportunities. This included examining the history of lotic CH_4 research, creating a database of concentrations and fluxes (MethDB) to generate a global-scale estimate of fluvial CH_4 efflux, and developing a conceptual framework and using this framework to consider how human activities may modify fluvial CH_4 dynamics. Current understanding of CH_4 in streams and rivers has been strongly influenced by goals of understanding OC processing and quantifying the contribution of CH_4 to ecosystem C fluxes. Less effort has been directed towards investigating processes that dictate in situ CH_4 production and loss. CH_4 makes a meager contribution to watershed or landscape C budgets, but streams and rivers are often significant CH_4 sources to the atmosphere across these same spatial extents. Most fluvial systems are supersaturated with CH_4 and we estimate an annual global emission of 26.8 Tg CH_4, equivalent to ~15-40% of wetland and lake effluxes, respectively. Less

Introduction

Sources and sinks of CH_4 in Tg CH_4 yr^{-1}



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

Introduction

nature geoscience

ARTICLES

https://doi.org/10.1038/s41561-021-00715-2

Check for updates

Half of global methane emissions come from highly variable aquatic ecosystem sources

Judith A. Rosentreter[1,2] ✉, Alberto V. Borges[3], Bridget R. Deemer[4], Meredith A. Holgerson[5,6,7], Shaoda Liu[2,8], Chunlin Song[9,10], John Melack[11], Peter A. Raymond[2], Carlos M. Duarte[12,13], George H. Allen[14], David Olefeldt[15], Benjamin Poulter[16], Tom I. Battin[17] and Bradley D. Eyre[1]

Atmospheric methane is a potent greenhouse gas that plays a major role in controlling the Earth's climate. The causes of the renewed increase of methane concentration since 2007 are uncertain given the multiple sources and complex biogeochemistry. Here, we present a metadata analysis of methane fluxes from all major natural, impacted and human-made aquatic ecosystems. Our revised bottom-up global aquatic methane emissions combine diffusive, ebullitive and/or plant-mediated fluxes from 15 aquatic ecosystems. We emphasize the high variability of methane fluxes within and between aquatic ecosystems and a positively skewed distribution of empirical data, making global estimates sensitive to statistical assumptions and sampling design. We find aquatic ecosystems contribute (median) 41% or (mean) 53% of total global methane emissions from anthropogenic and natural sources. We show that methane emissions increase from natural to impacted aquatic ecosystems and from coastal to freshwater ecosystems. We argue that aquatic emissions will probably increase due to urbanization, eutrophication and positive climate feedbacks and suggest changes in land-use management as potential mitigation strategies to reduce aquatic methane emissions.

Introduction

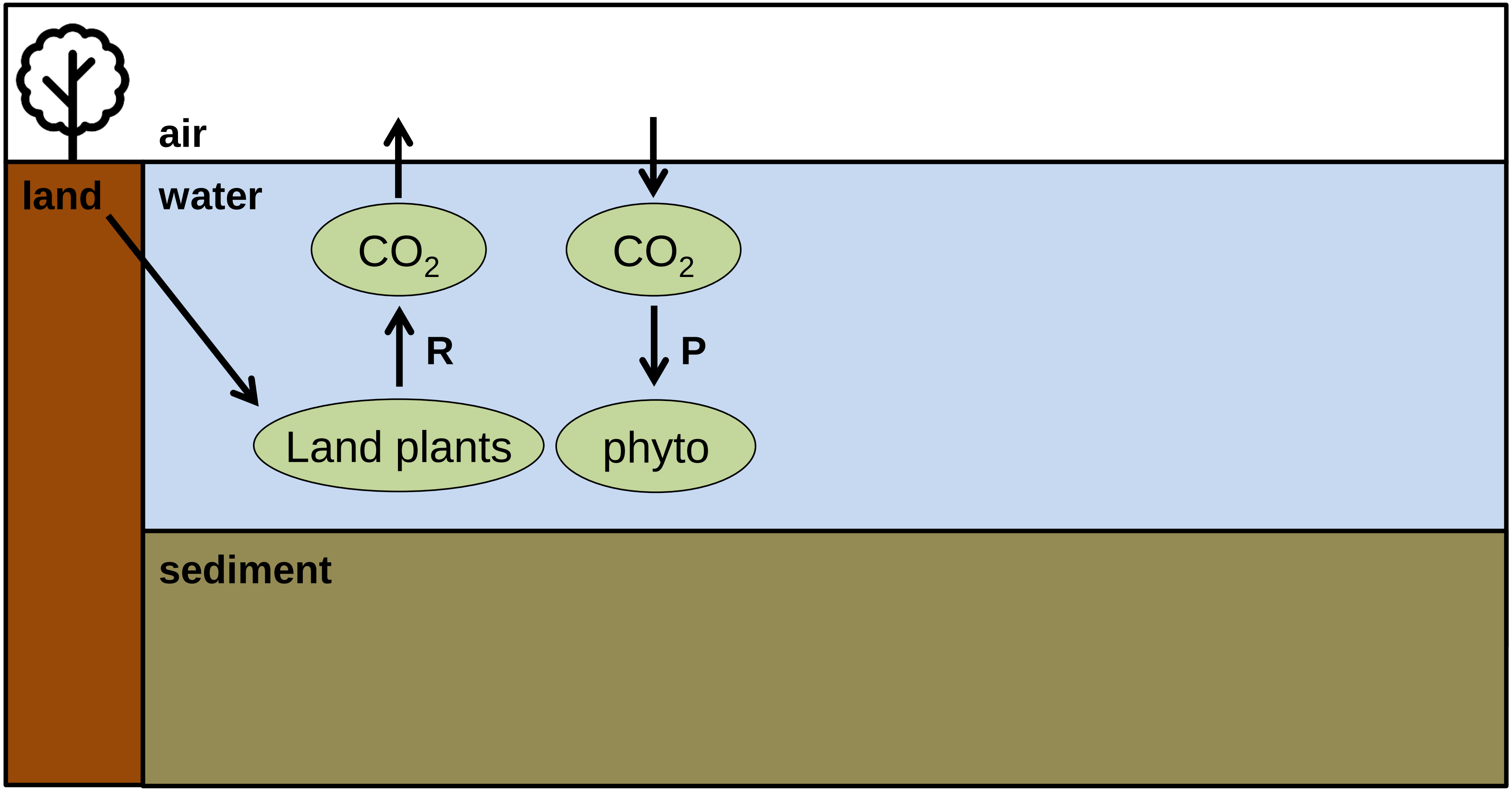
CO_2 and CH_4 in lakes

Introduction

CO_2 and CH_4 in lakes

Introduction

Does this change from one lake to another ?



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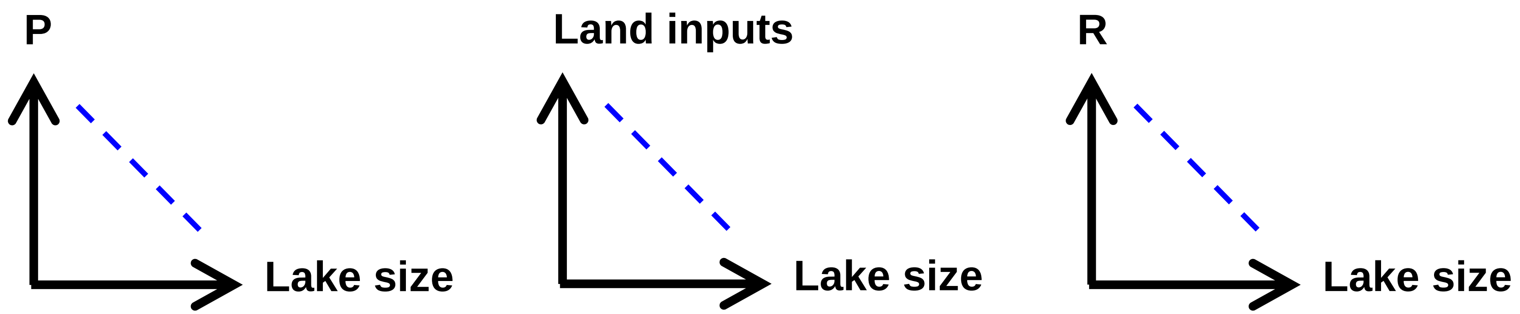

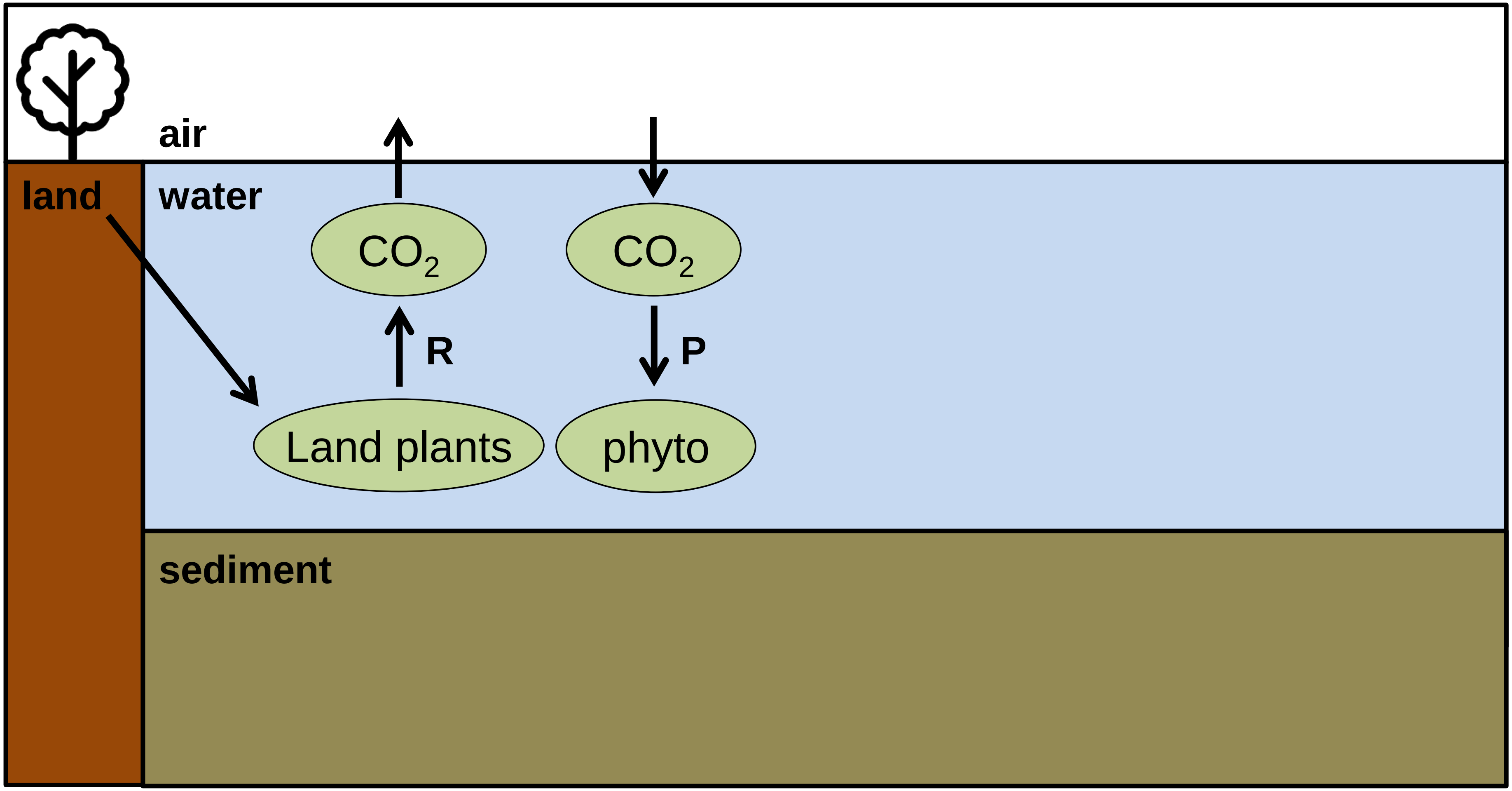

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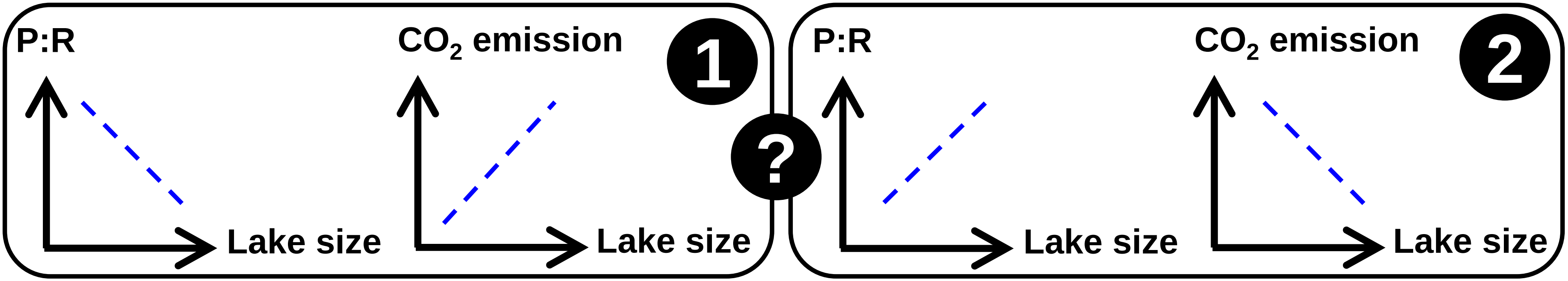
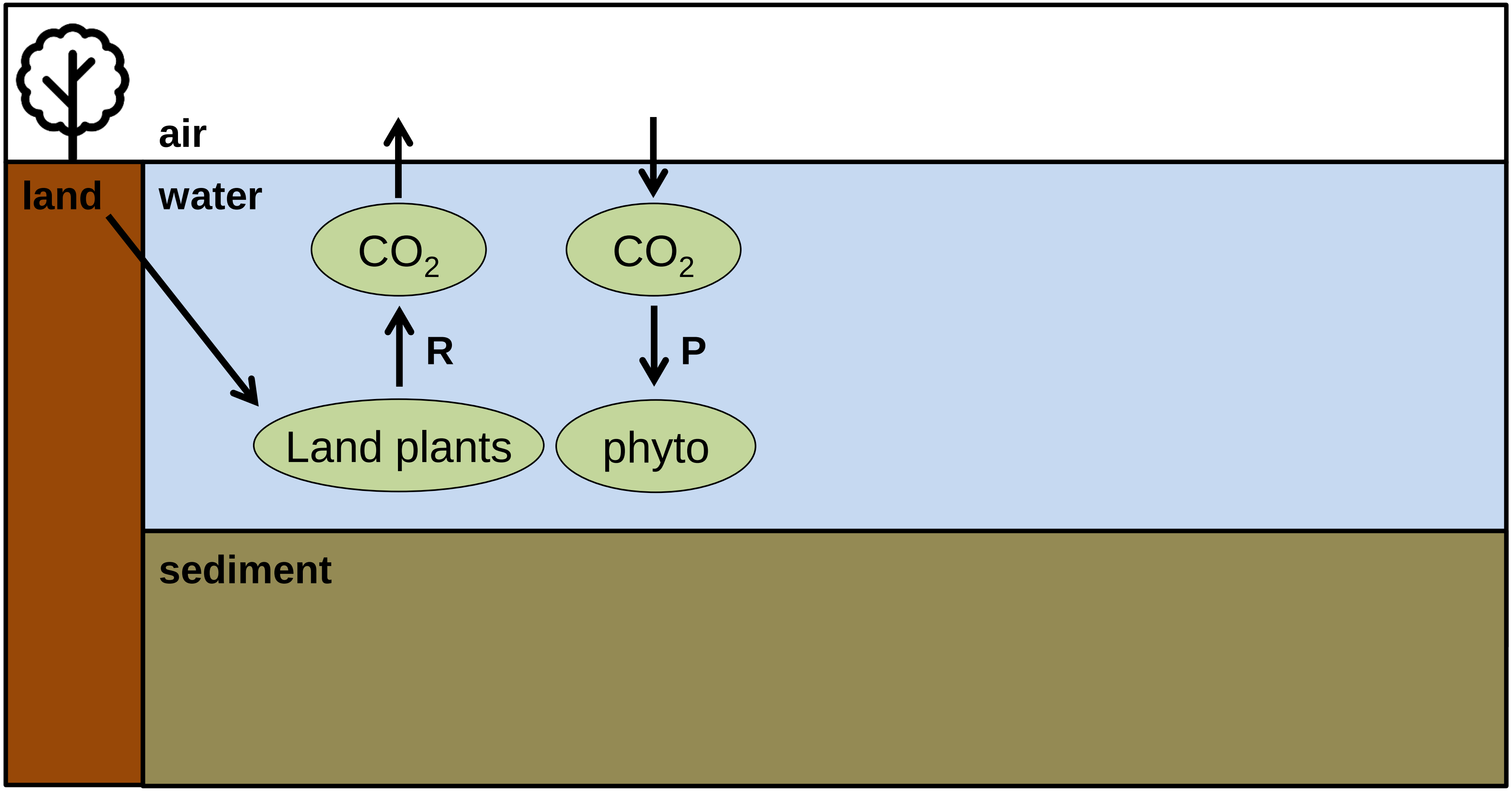
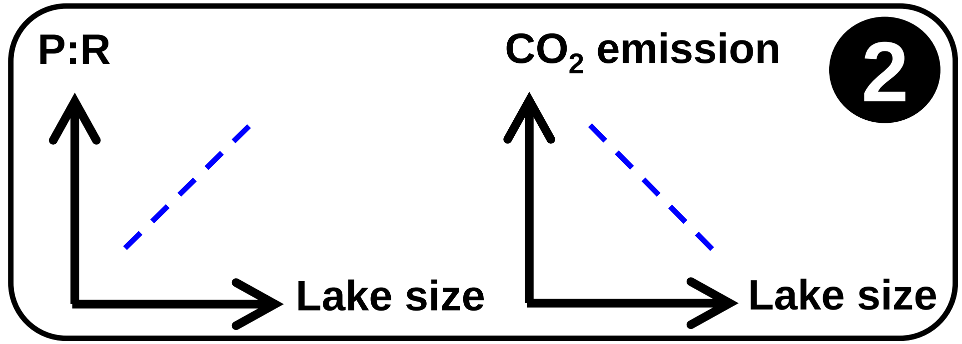




Introduction



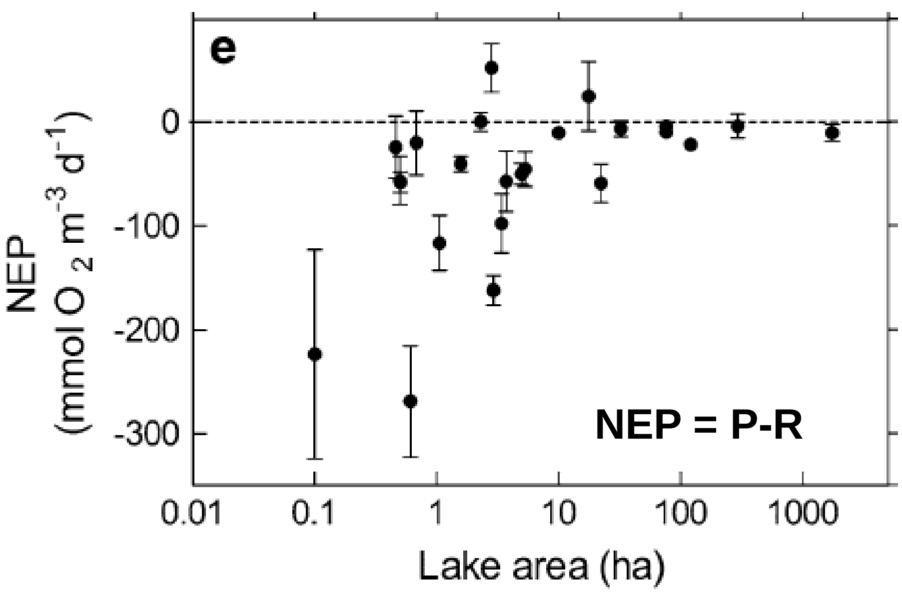
In boreal lakes this is the scenario

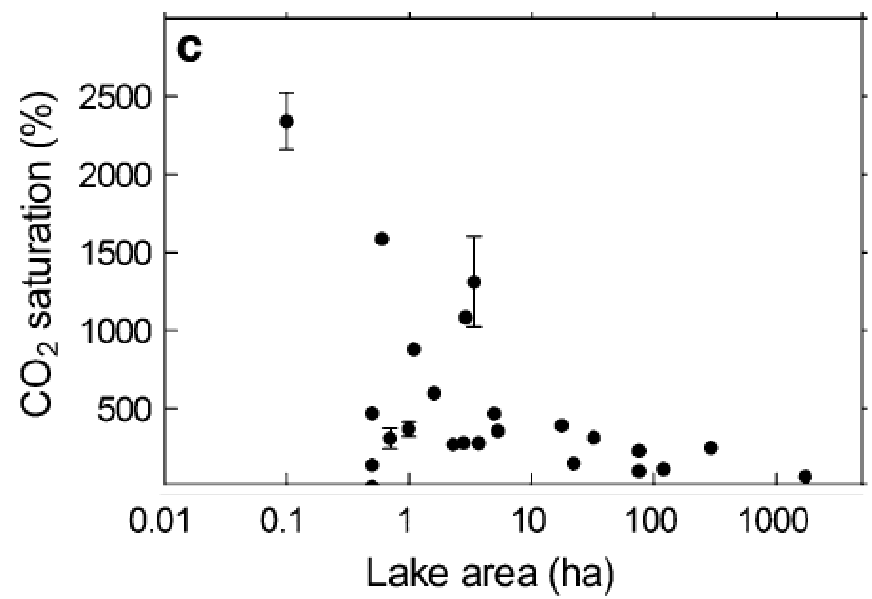
Aquat Sci (2012) 74:155–169
DOI 10.1007/s00027-011-0207-6
Aquatic Sciences

RESEARCH ARTICLE

Lake metabolism scales with lake morphometry and catchment conditions

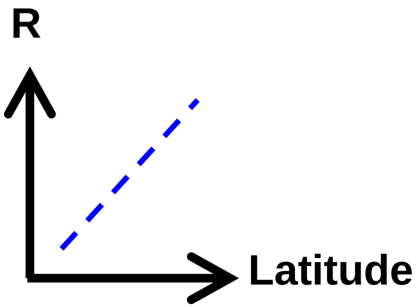
Peter A. Staehr · Lars Baastrup-Spohr ·
Kaj Sand-Jensen · Colin Stedmon

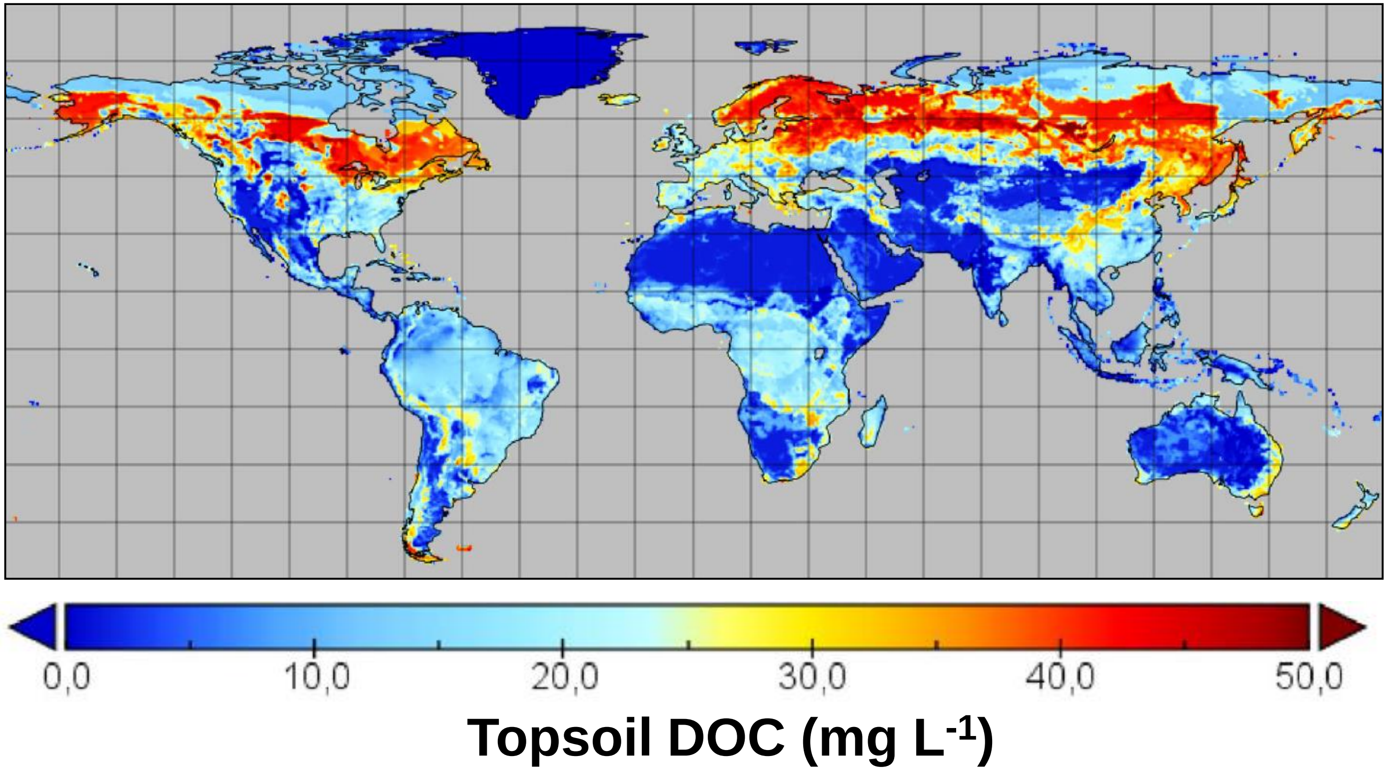




Introduction

Lake size matters but what about latitude and climate ?





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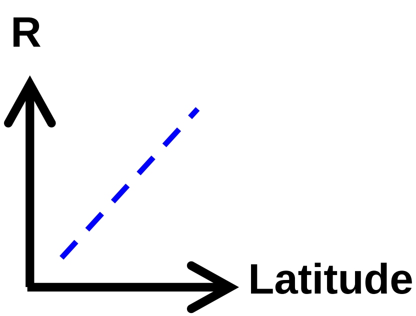

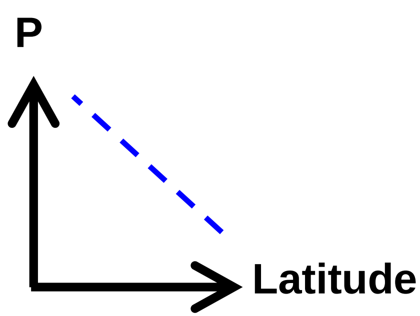

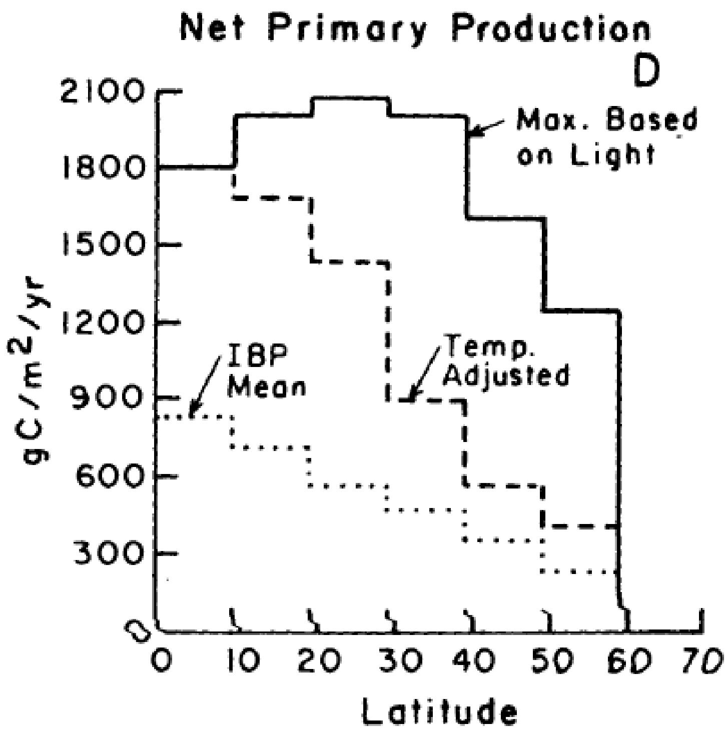

Ann. Rev. Ecol. Syst. 1987. 18:159–84
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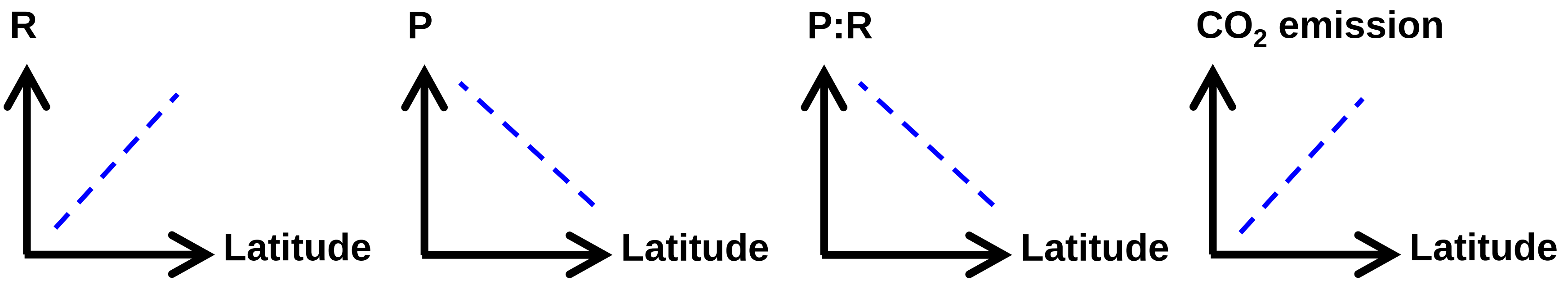
TROPICAL LIMNOLOGY

William M. Lewis, Jr.

Introduction

Lake size matters but what about latitude and climate ?



In theory, but needs to be checked by field data.

Introduction

Thématique de recherche ← **Affinités personnelles** / **Environnement institutionnel**

↓

Hypothèse de travail ← **Littérature existante** (Google Scholar, ResearchGate)

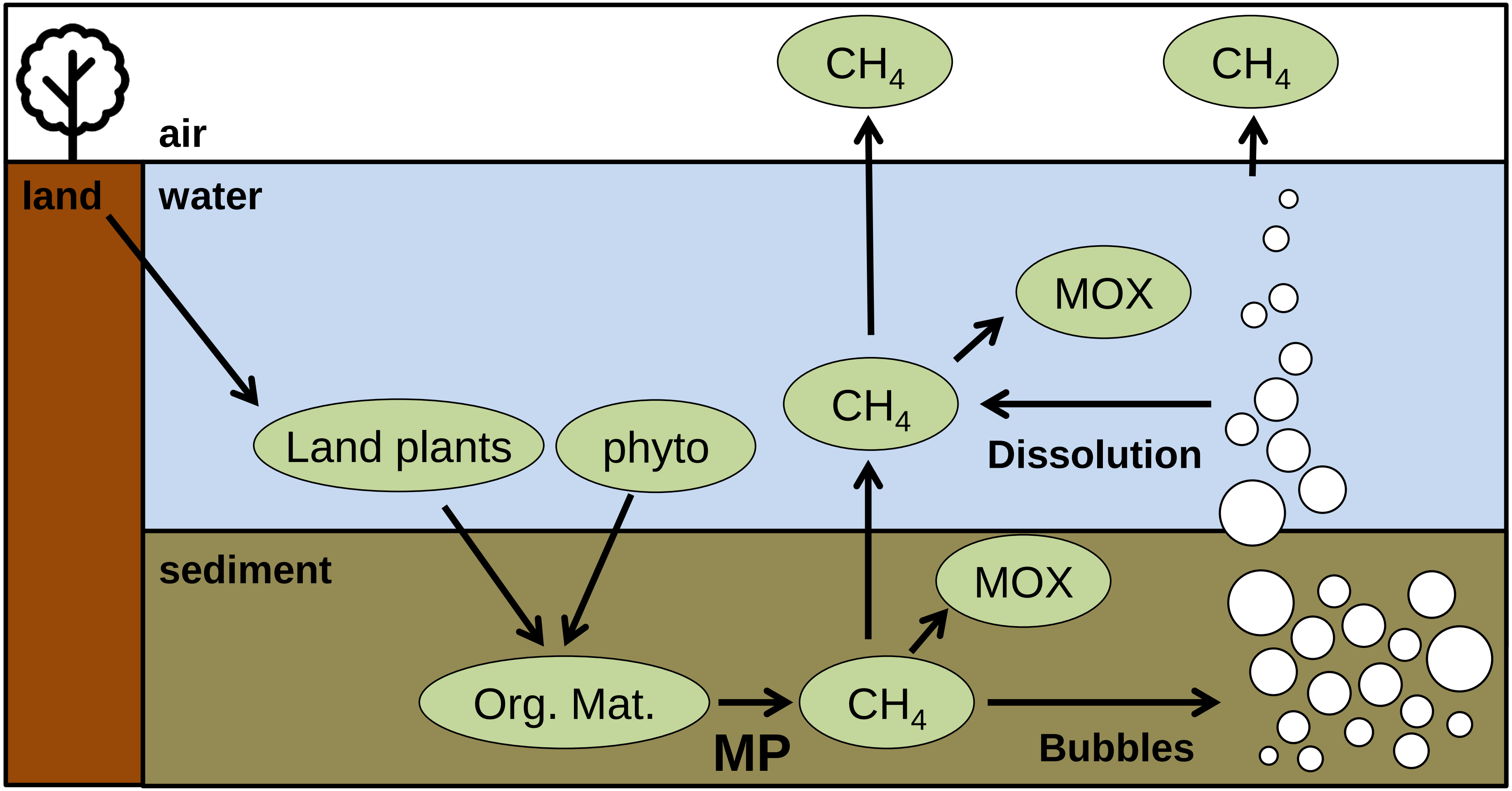
↑

Test par expérimentation ← **Mesures de terrain** / **Mesures en laboratoire** / **Modélisation numérique**

Introduction

CO_2 and CH_4 in lakes

Introduction



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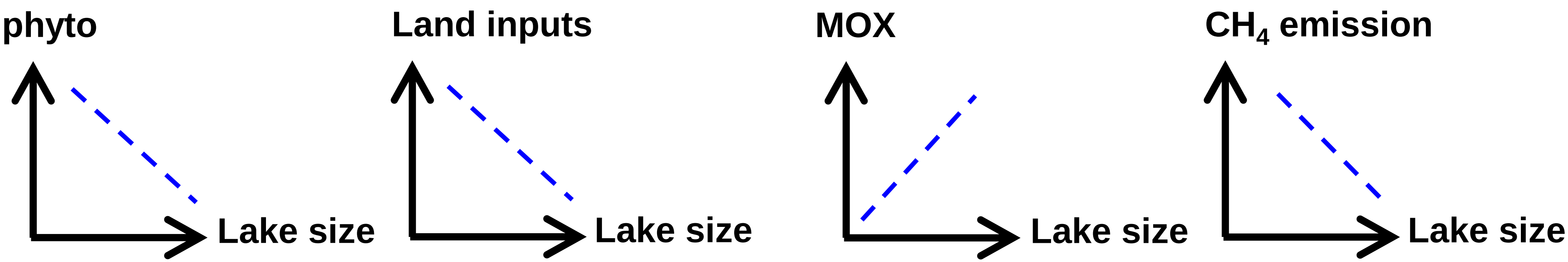

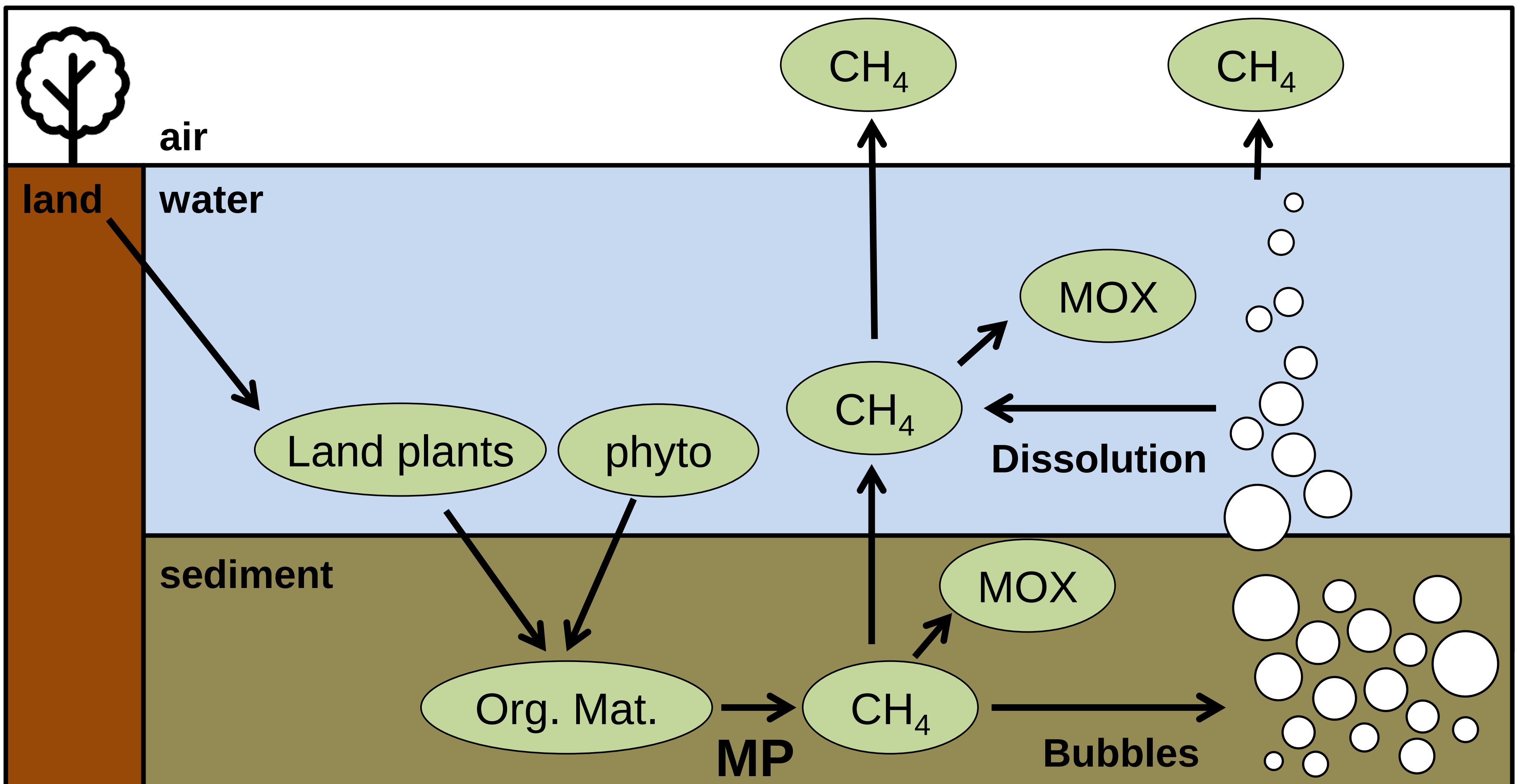

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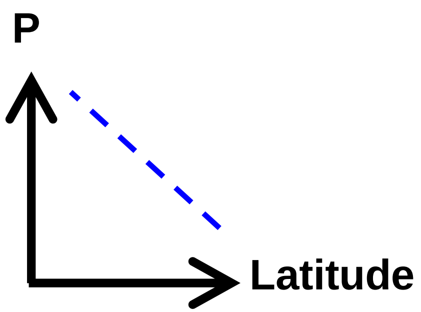

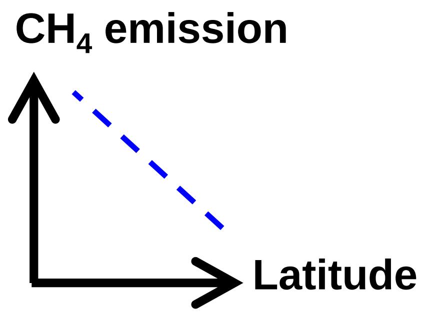

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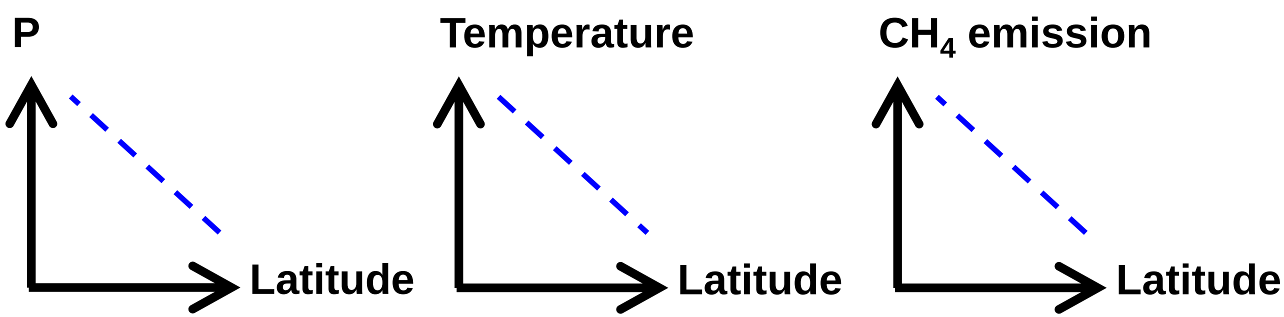


Temperature dependence of methane production from different precursors in a profundal sediment (Lake Constance)

Silke Schulz, Hidetoshi Matsuyama [1], Ralf Conrad *

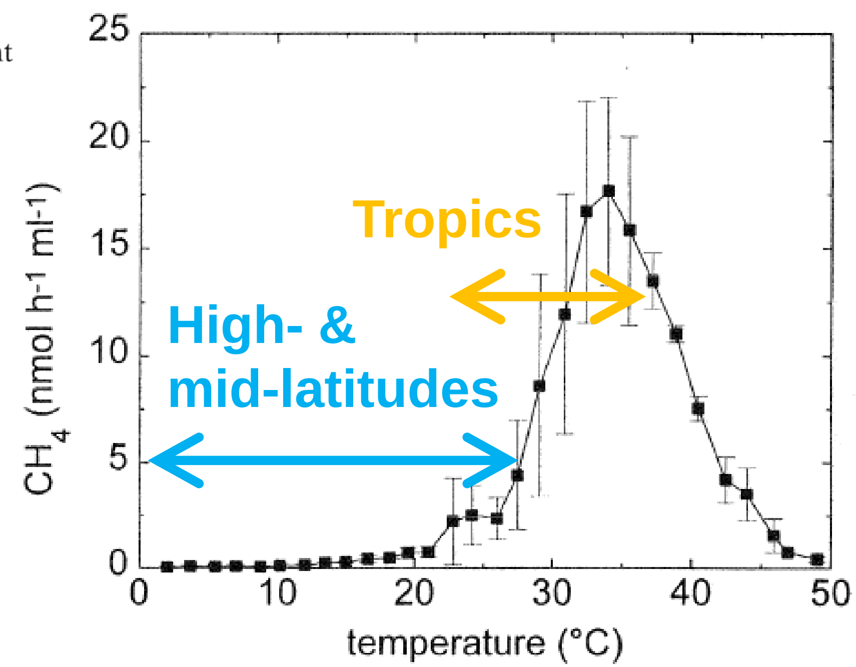
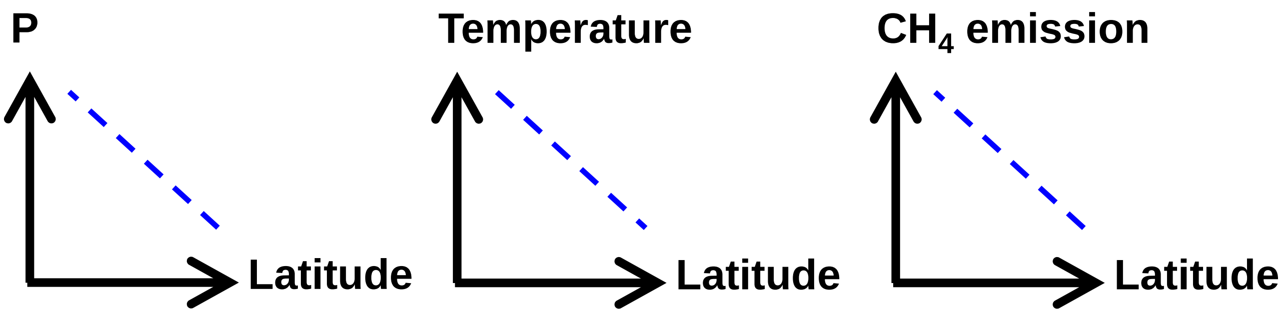


Fig. 1. Methane production rates in slurries (1 ml = 0.13 g dry weight) of unamended profundal sediment of Lake Constance as a function of incubation temperature. Mean ± SD of $n = 6$.

Introduction

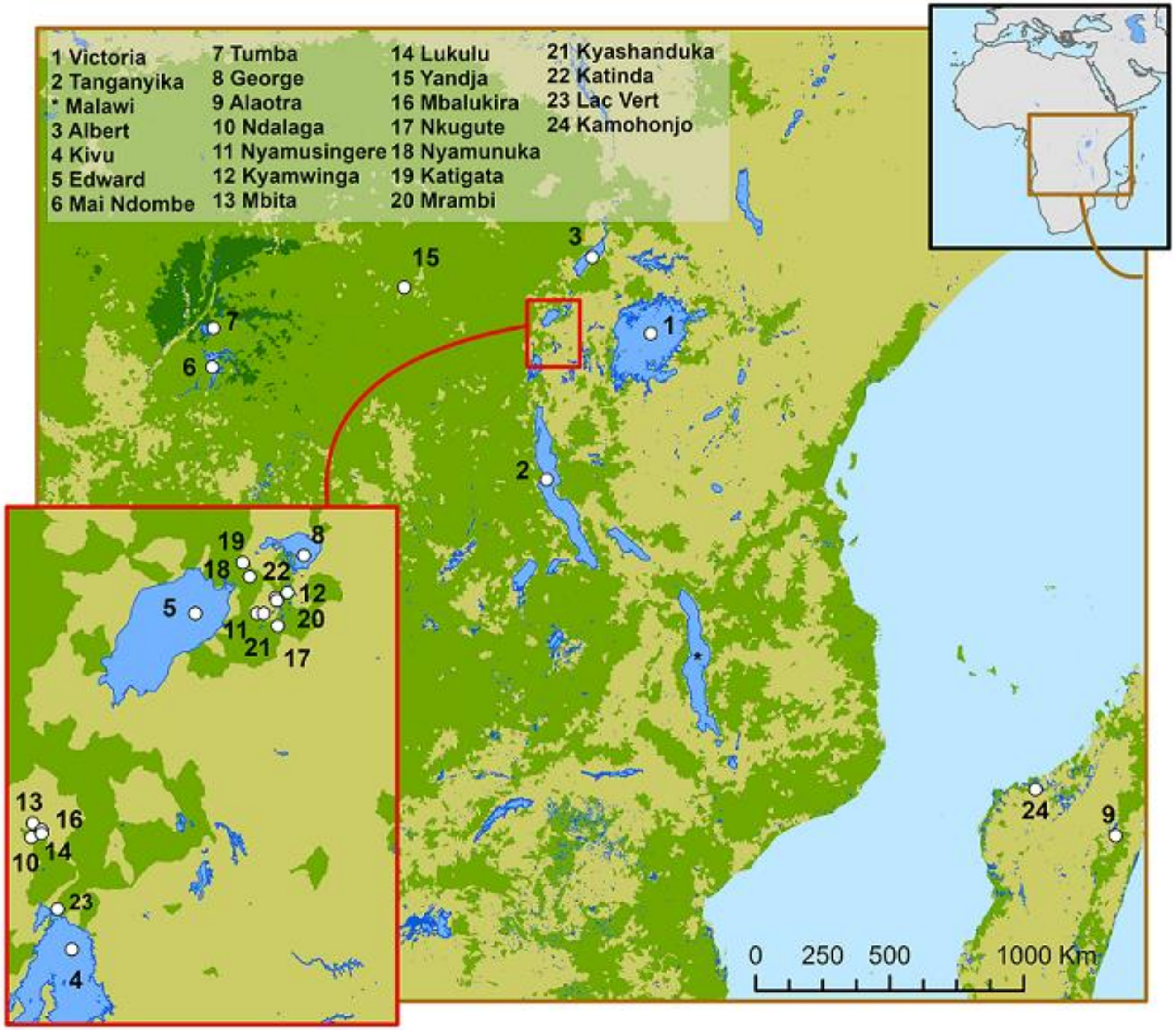
Lake size matters but what about latitude and climate ?



In theory, but needs to be checked by field data.

CO_2 and CH_4 emissions from African lakes

CO_2 and CH_4 emissions from African lakes



Land cover

- Flooded forest
- Rain forest
- Savannah

Surface area

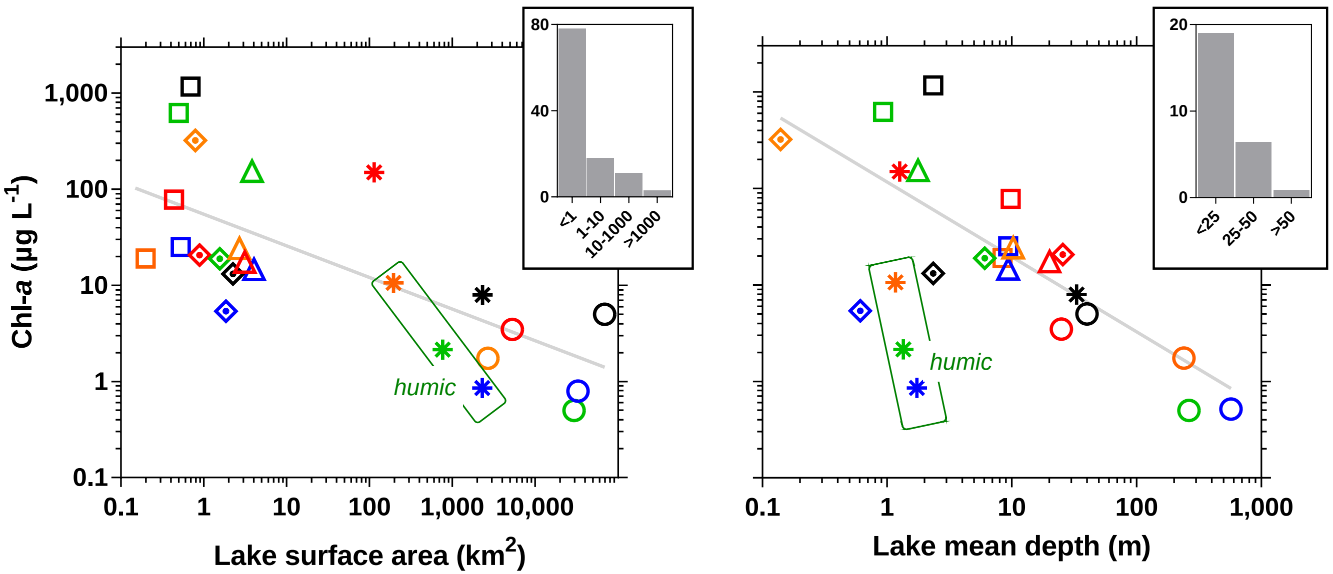
- Victoria 67,000 km^2
- Lac Vert 0.2 km^2

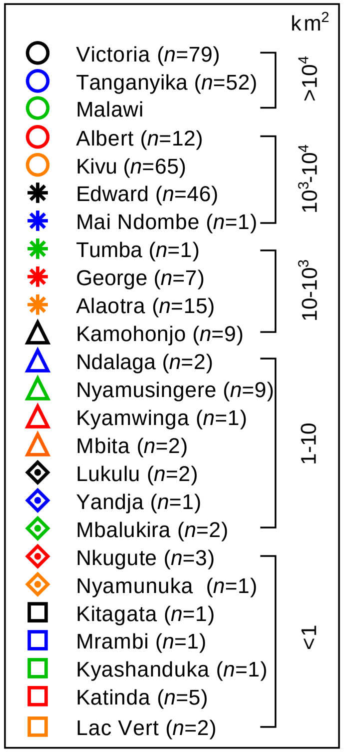
Max depth

- Tanganyika 1,470 m
- Nyamunuka 0.1 m

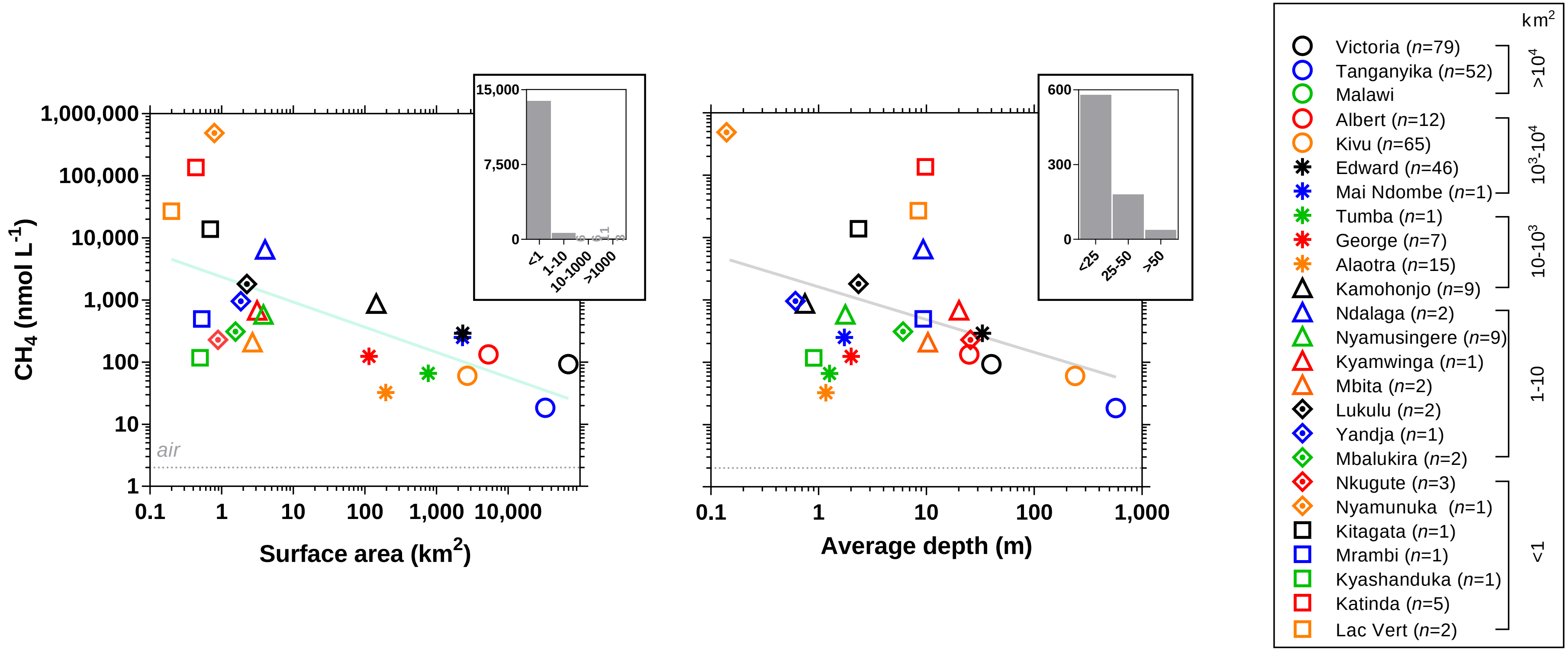
CO_2 and CH_4 emissions from African lakes

Chlorophyll-a 0.5 to 1,170 µg L^{-1}





CO_2 and CH_4 emissions from African lakes



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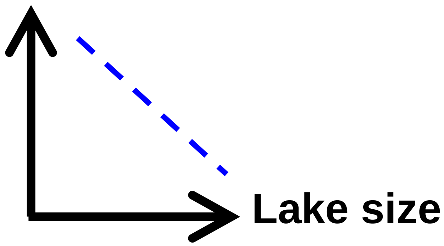
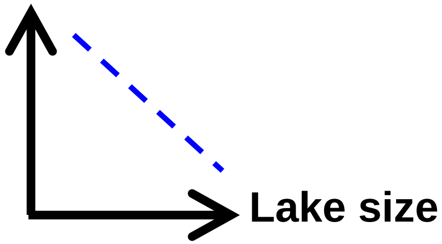
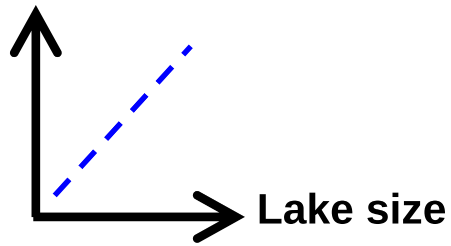


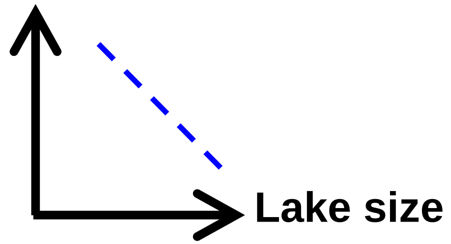
Land inputs



MOX



CH_4 emission



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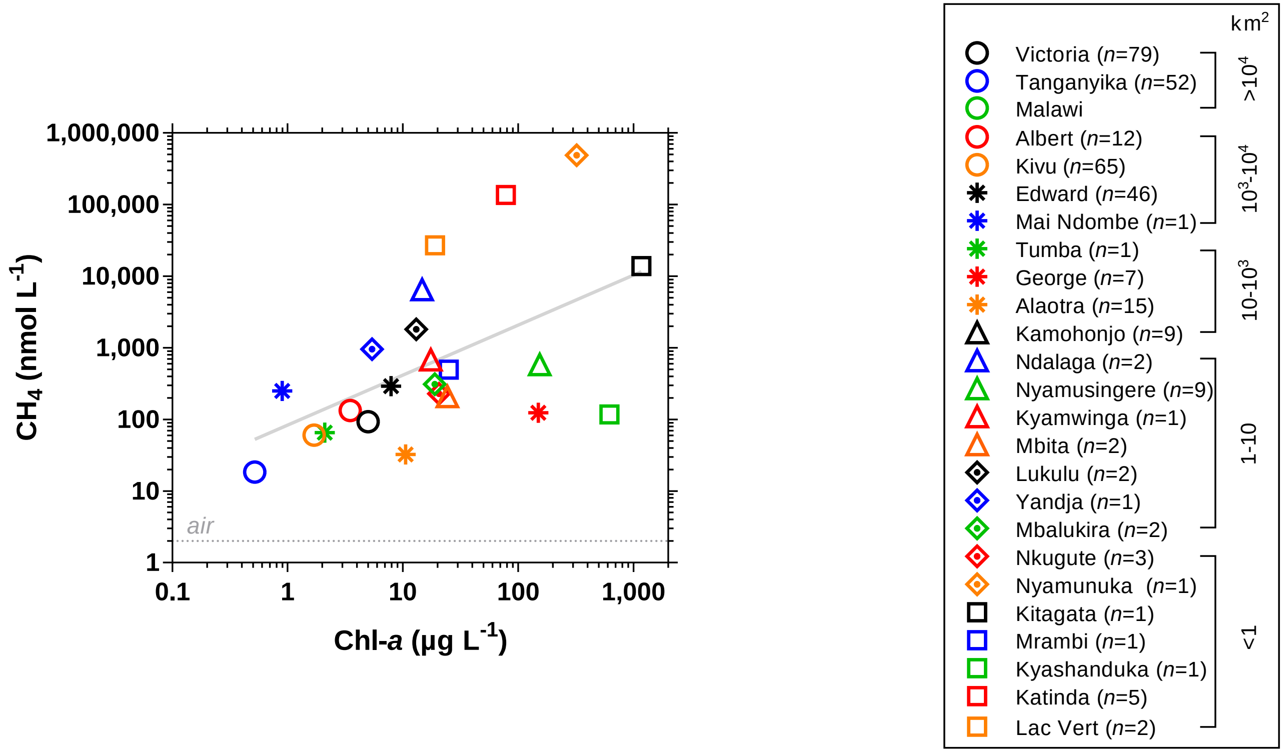
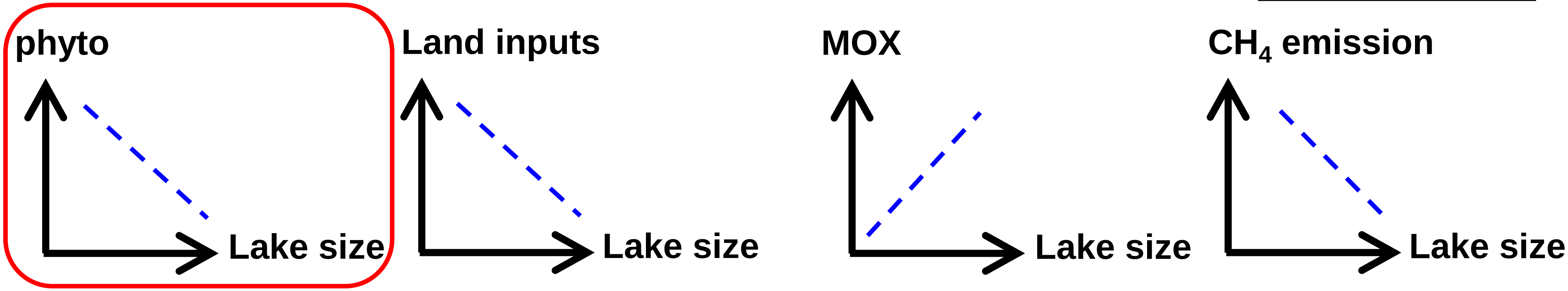
CO_2 and CH_4 emissions from African lakes





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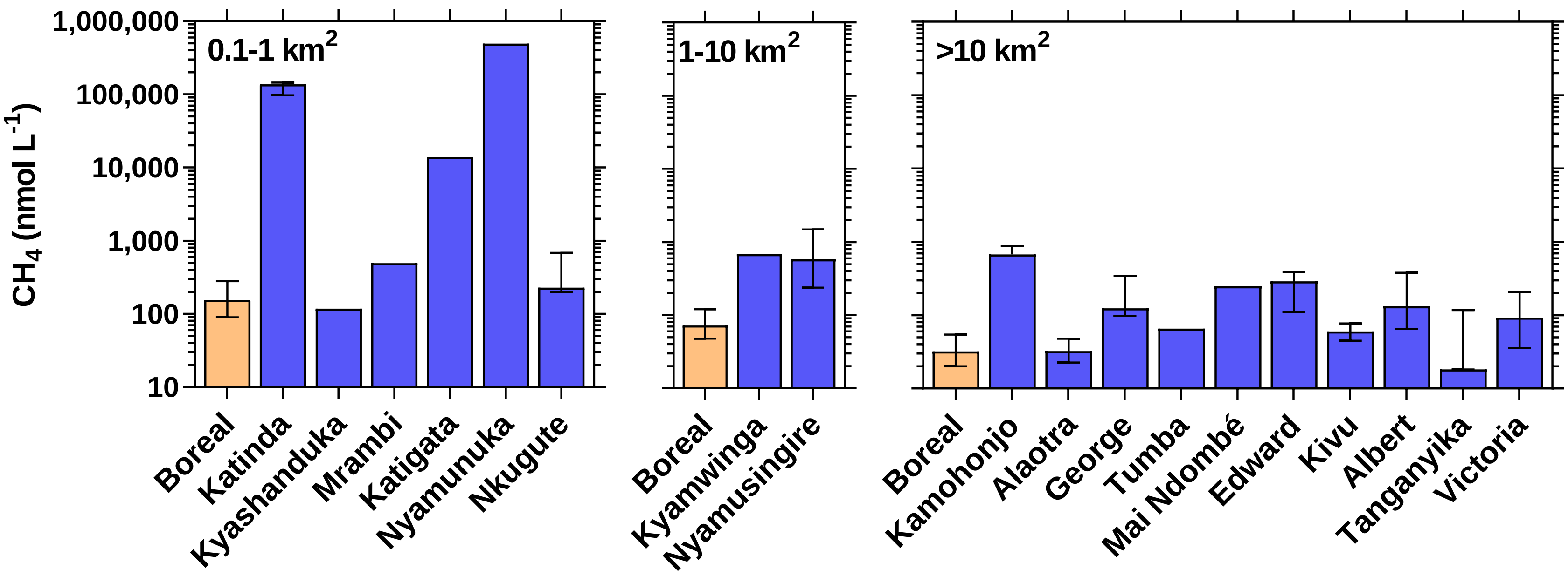

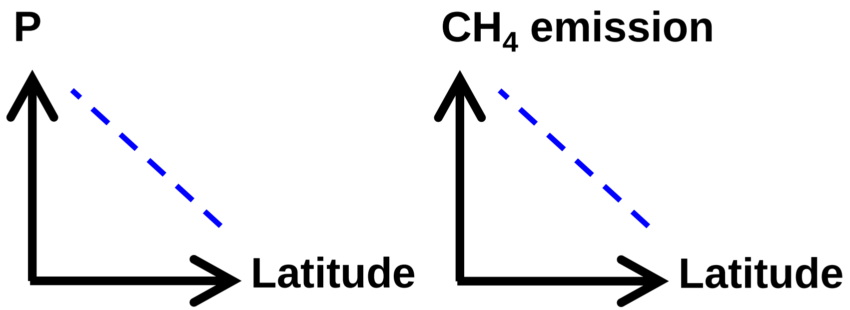

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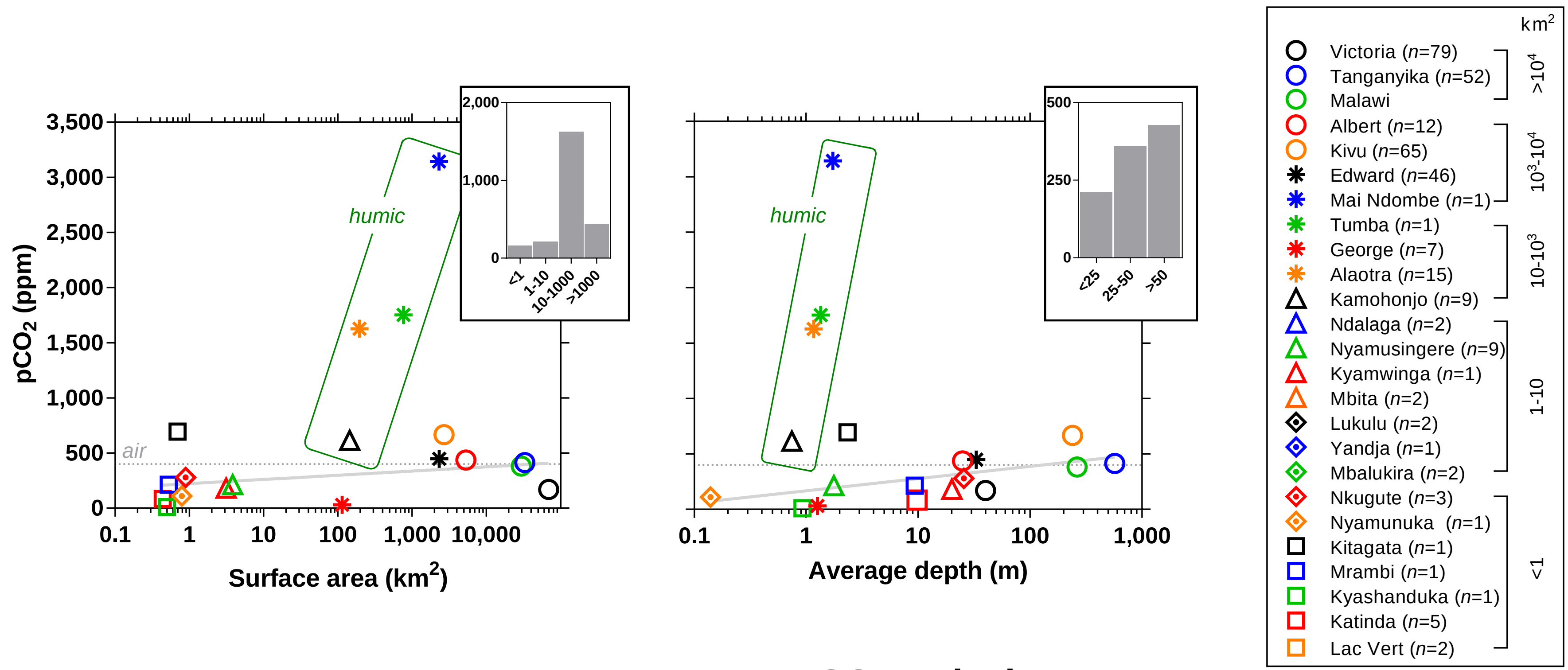

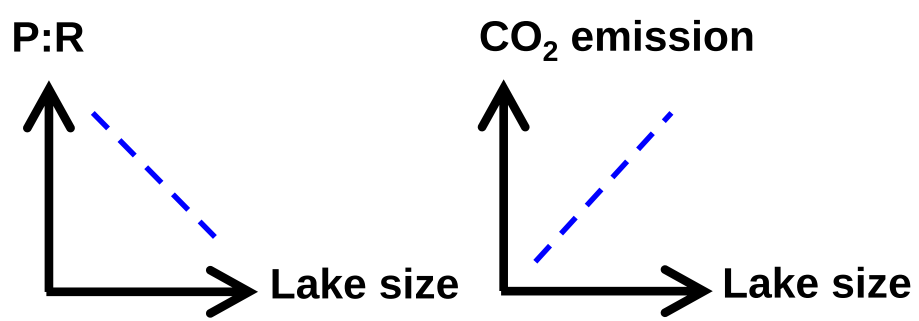

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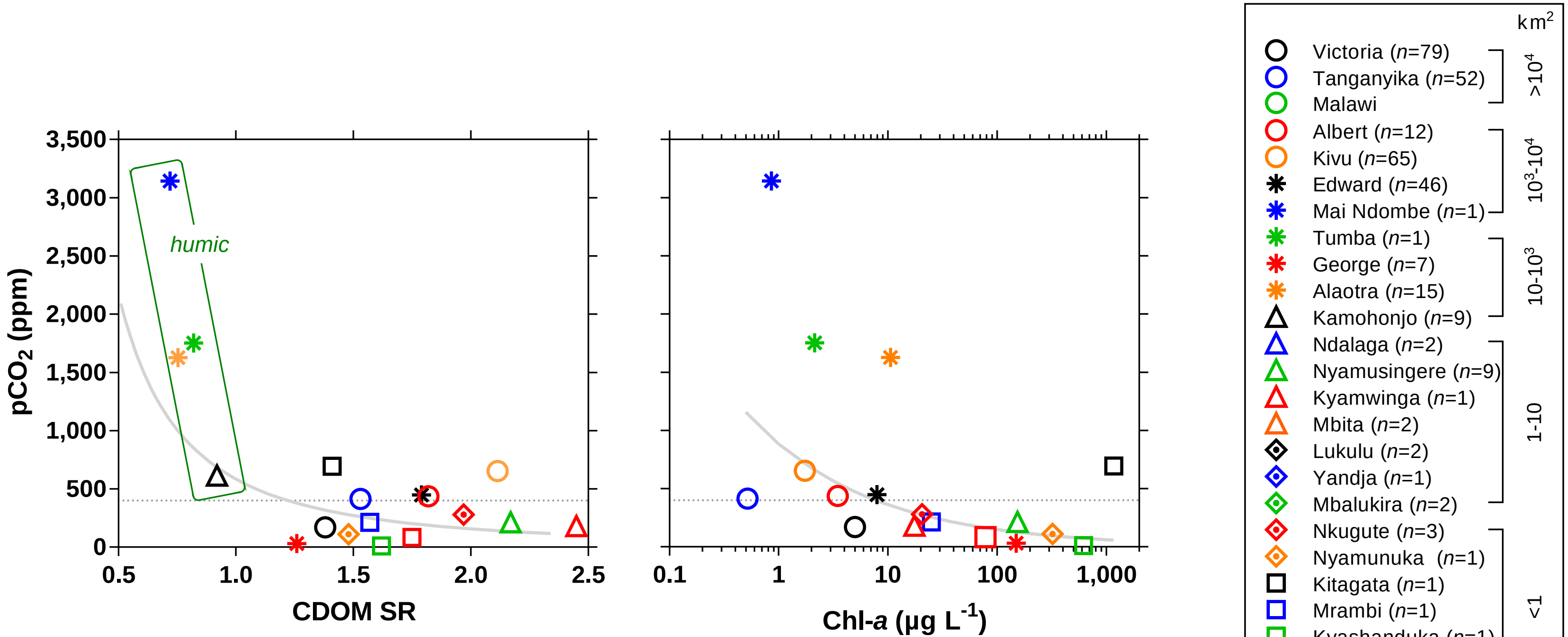

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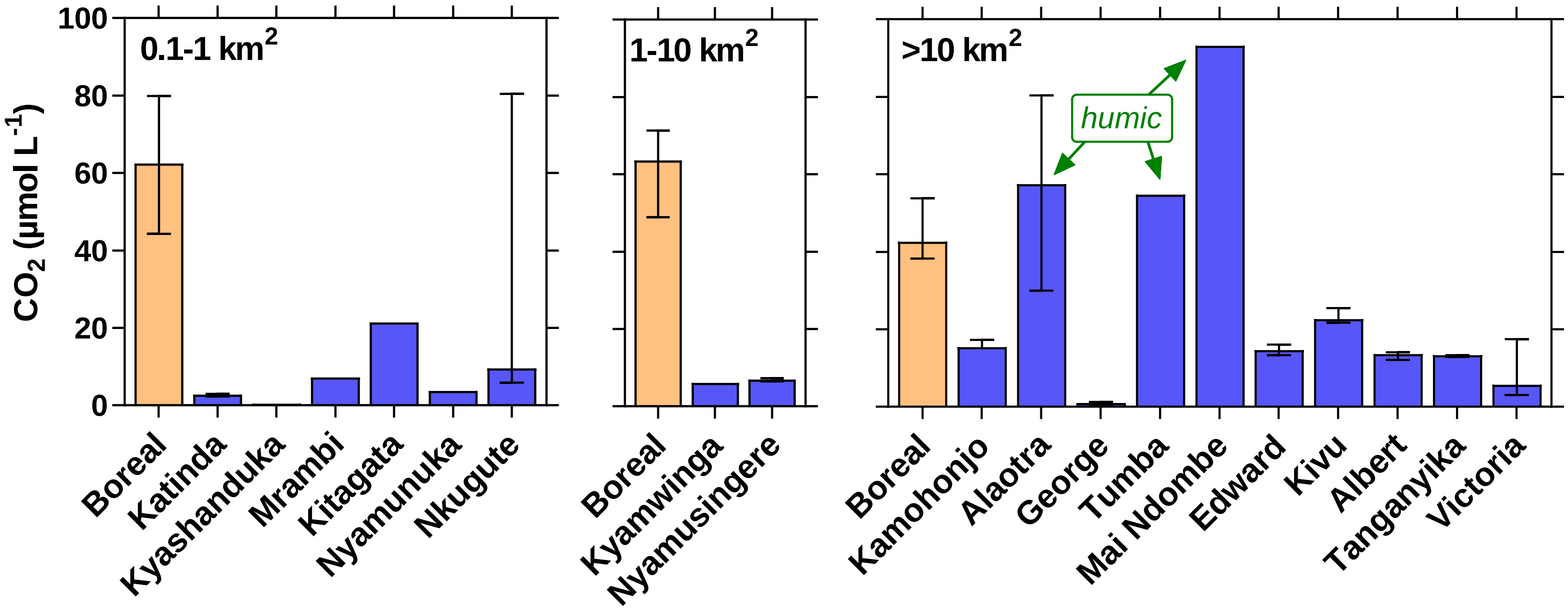

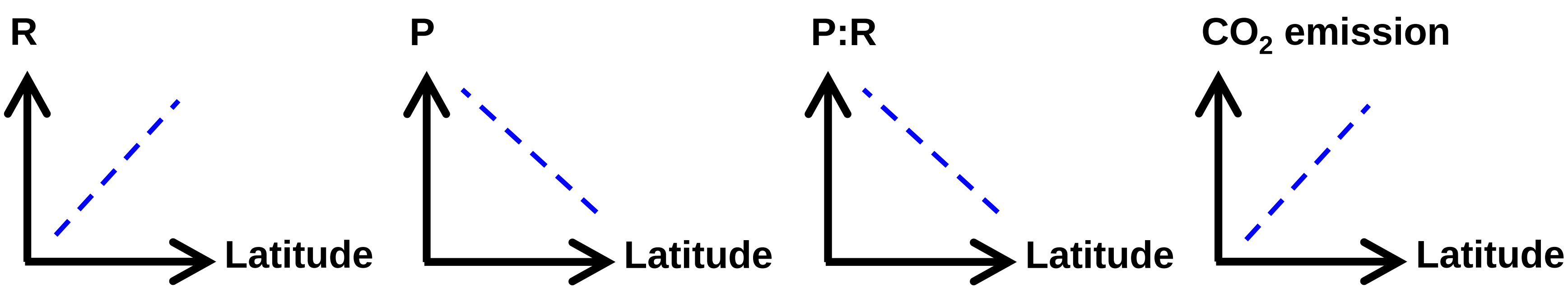

Theory WAS checked by field data.

CO_2 and CH_4 emissions from African lakes

SCIENCE ADVANCES | RESEARCH ARTICLE

ENVIRONMENTAL STUDIES

Greenhouse gas emissions from African lakes are no longer a blind spot

Alberto V. Borges[1]*, Loris Deirmendjian[1]†, Steven Bouillon[2], William Okello[3], Thibault Lambert[1]‡, Fleur A. E. Roland[1], Vao F. Razanamahandry[2], Ny Riavo G. Voarintsoa[2]§, François Darchambeau[1]¶, Ismael A. Kimirei[4], Jean-Pierre Descy[1], George H. Allen[5], Cédric Morana[1,2]

Natural lakes are thought to be globally significant sources of greenhouse gases (CO_2, CH_4, and N_2O) to the atmosphere although nearly no data have been previously reported from Africa. We collected CO_2, CH_4, and N_2O data in 24 African lakes that accounted for 49% of total lacustrine surface area of the African continent and covered a wide range of morphology and productivity. The surface water concentrations of dissolved CO_2 were much lower than values attributed in current literature to tropical lakes and lower than in boreal systems because of a higher productivity. In contrast, surface water–dissolved CH_4 concentrations were generally higher than in boreal systems. The lowest CO_2 and the highest CH_4 concentrations were observed in the more shallow and productive lakes. Emissions of CO_2 may likely have been substantially overestimated by a factor between 9 and 18 in African lakes and between 6 and 26 in pan-tropical lakes.

CO_2 and CH_4 emissions from African lakes

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