Variations of dissolved greenhouse gases (CO_2, CH_4, N_2O) in the Congo River network overwhelmingly driven by fluvial wetland connectivity

Alberto V. Borges

LIÈGE université

Lab presentation

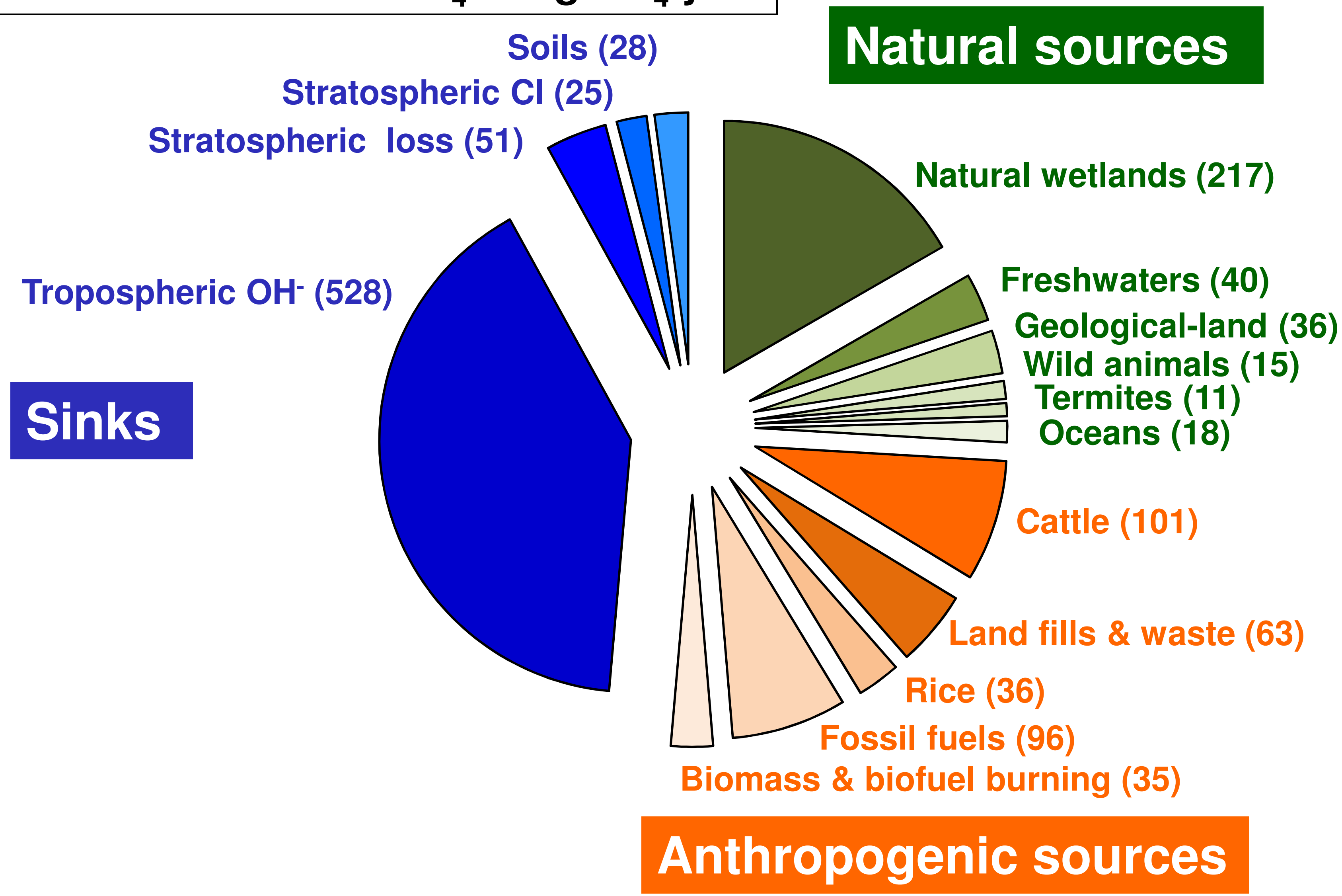
Lab presentation

- Lab = 2 permanent researchers, 6 Post-docs, 4 PhD students
- Measurements of CO_2, CH_4, N_2O in aquatic enviroments
- Personal emphasis on African lakes and rivers (since 2007)

CH_4 emissions from rivers

Introduction

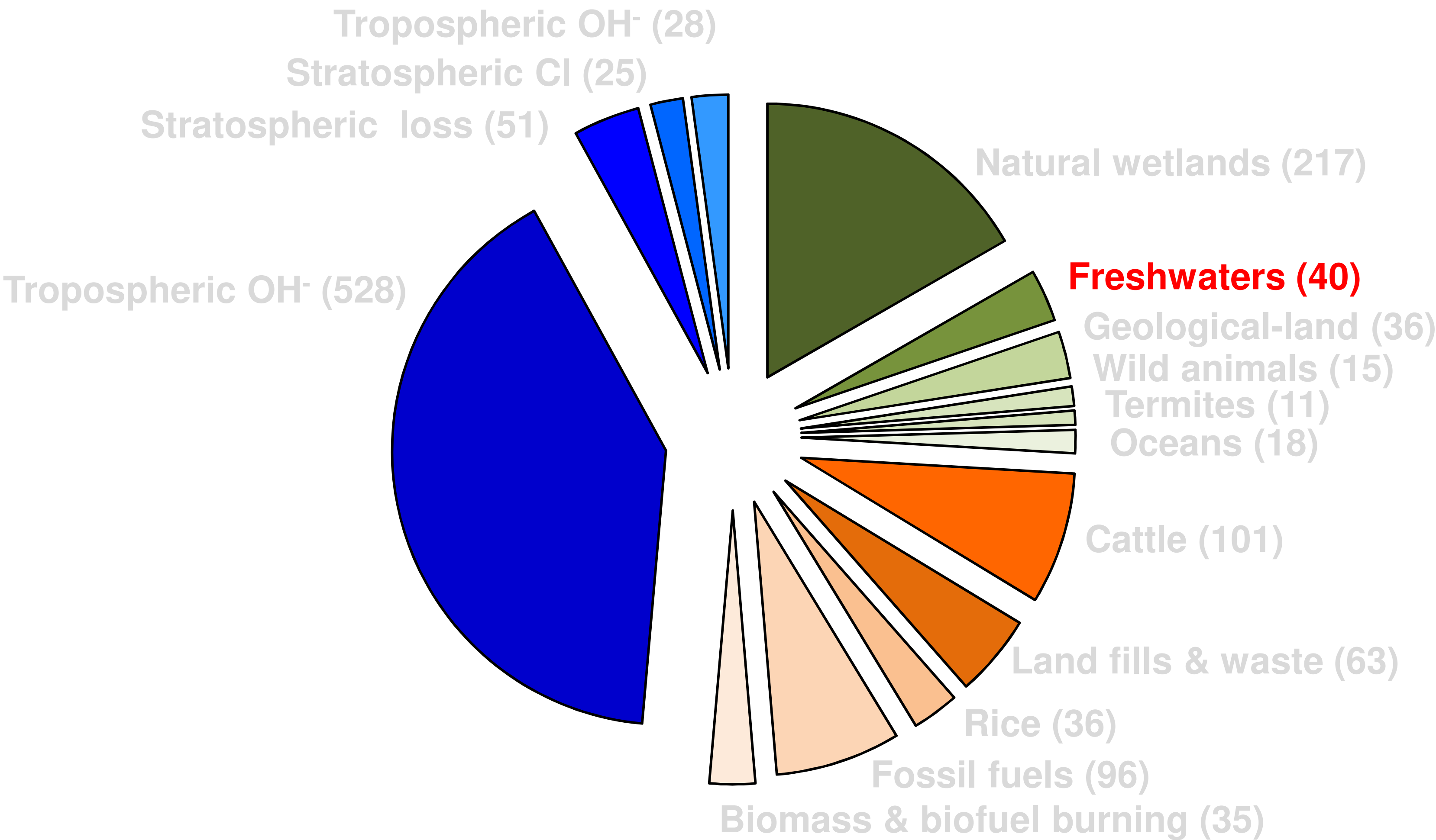
Sources and sinks of CH_4 in Tg CH_4 yr^{-1}



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

Introduction

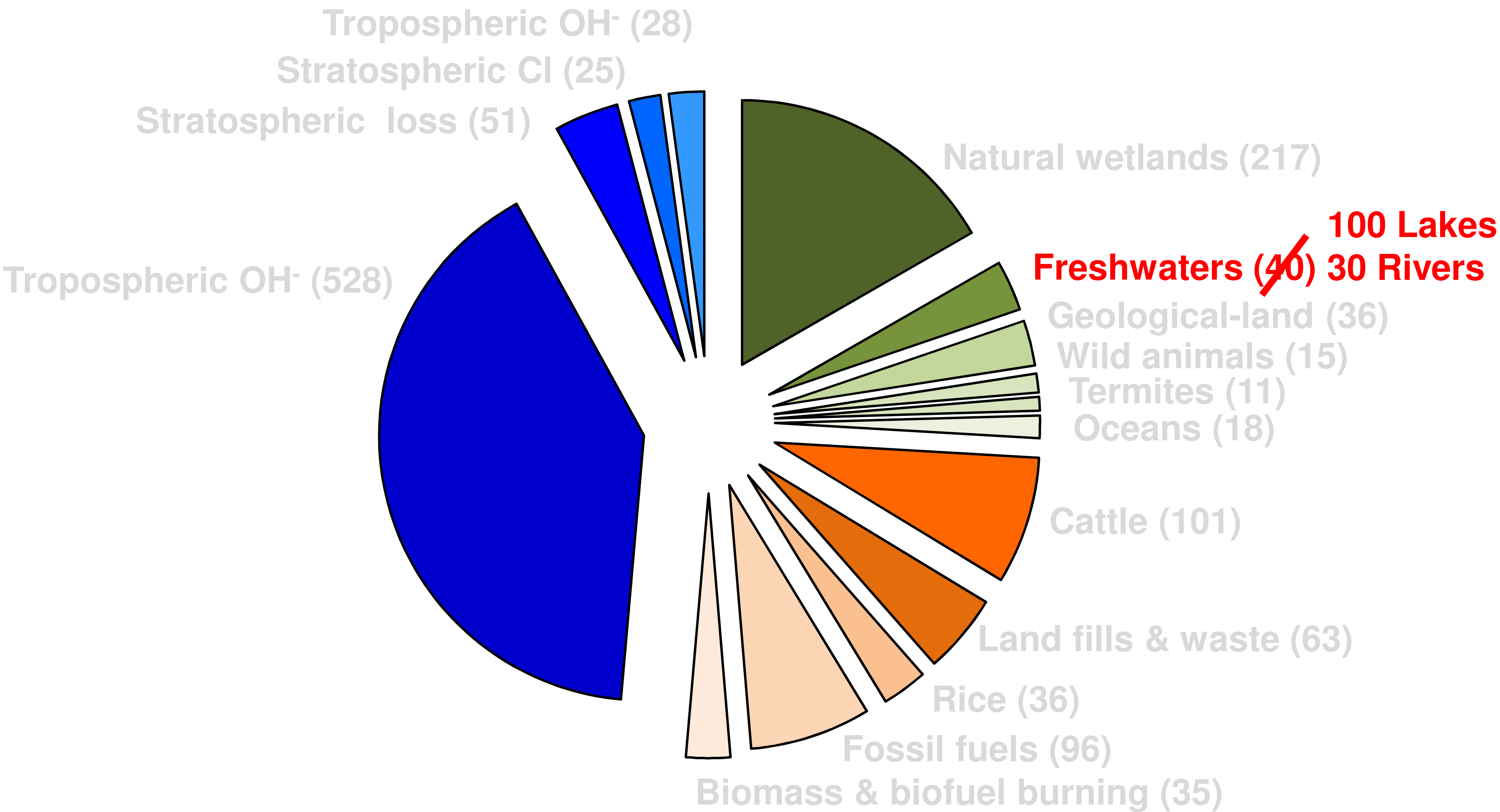
Sources and sinks of CH_4 in Tg CH_4 yr^{-1}



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

Introduction

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



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

CO_2 emissions from rivers

Introduction

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 $PgC\ y^{-1}$ +

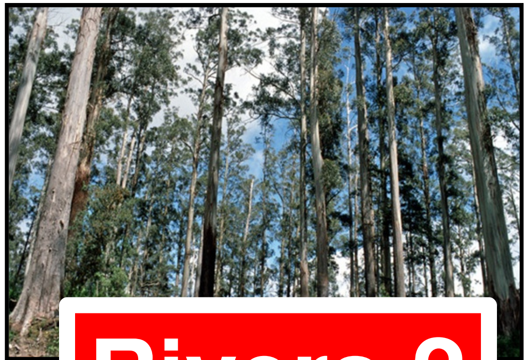
5.0±0.2 $PgC\ y^{-1}$

50%

2.6±1.0 $PgC\ y^{-1}$

26%

Calculated as the residual of all other flux components



Rivers ?

24%

2.4±0.5 $PgC\ y^{-1}$

Average of 5 models

www.globalcarbonproject.org/

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]

River CO_2 global emission

1.8 PgC yr^{-1} (Raymond et al. 2013)

0.7 PgC yr^{-1} (Lauerwald et al. 2015)

Global carbon dioxide emissions from inland waters

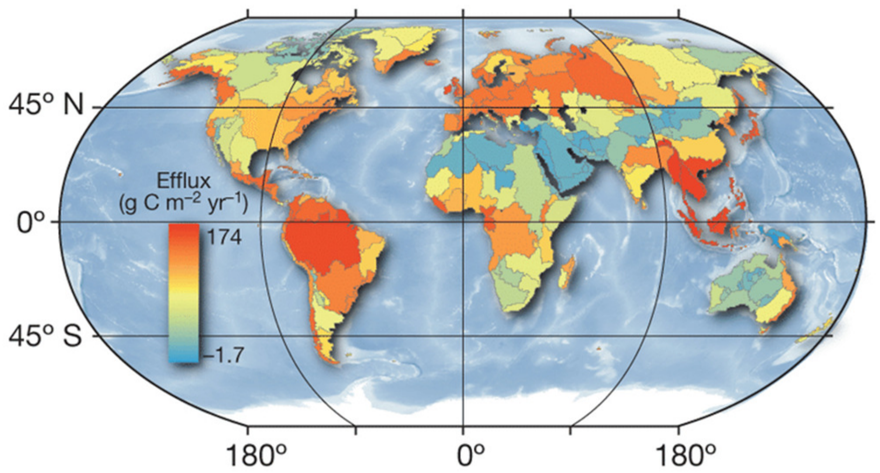
Peter A. Raymond[1], Jens Hartmann[2*], Ronny Lauerwald[2,3*], Sebastian Sobek[4*], Cory McDonald[5], Mark Hoover[1], David Butman[1,6], Robert Striegl[6], Emilio Mayorga[7], Christoph Humborg[8], Pirkko Kortelainen[9], Hans Dürr[10], Michel Meybeck[11], Philippe Ciais[12] & Peter Guth[13]

Spatial patterns in CO_2 evasion from the global river network

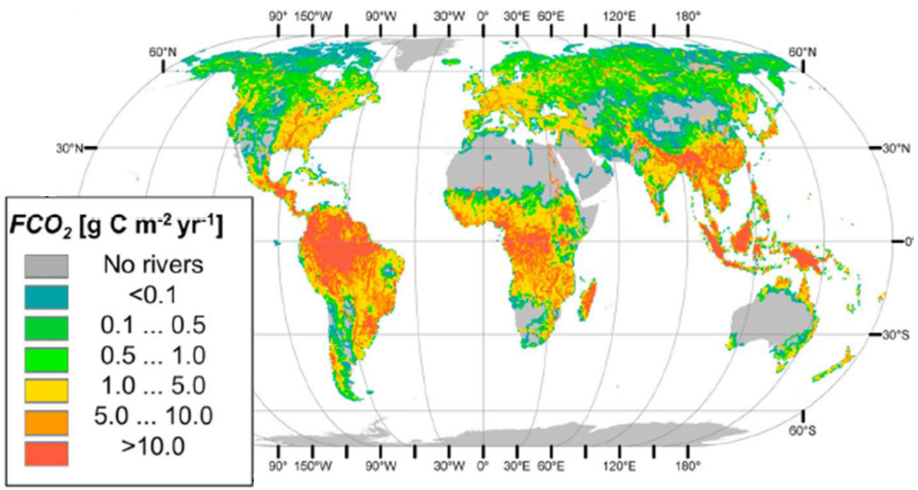
Ronny Lauerwald[1,2,3], Goulven G. Laruelle[1,4], Jens Hartmann[3], Philippe Ciais[5], and Pierre A. G. Regnier[1]

Introduction

Raymond et al. (2013)

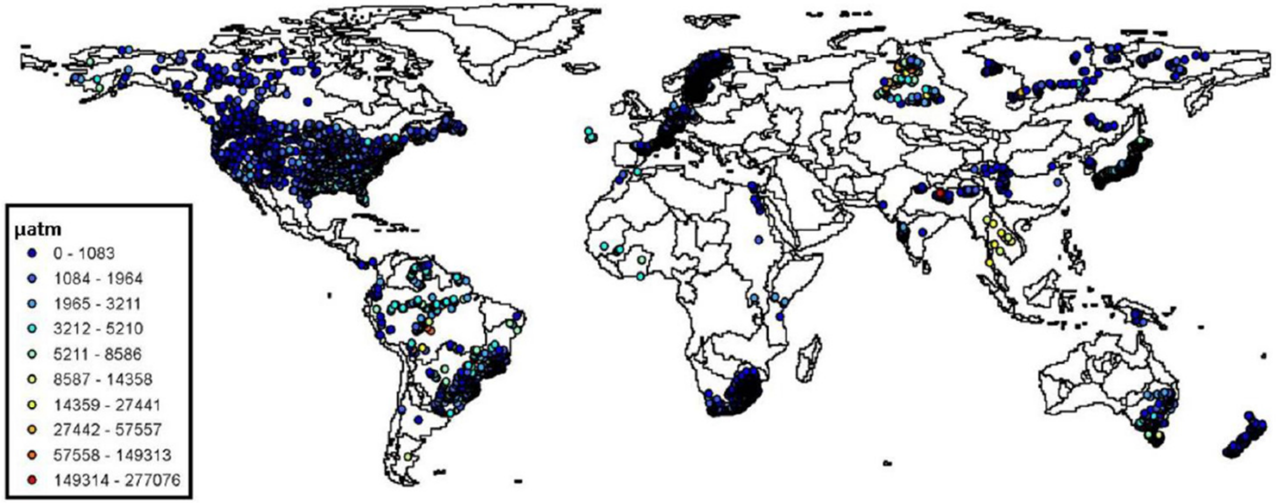


Lauerwald et al. (2015)

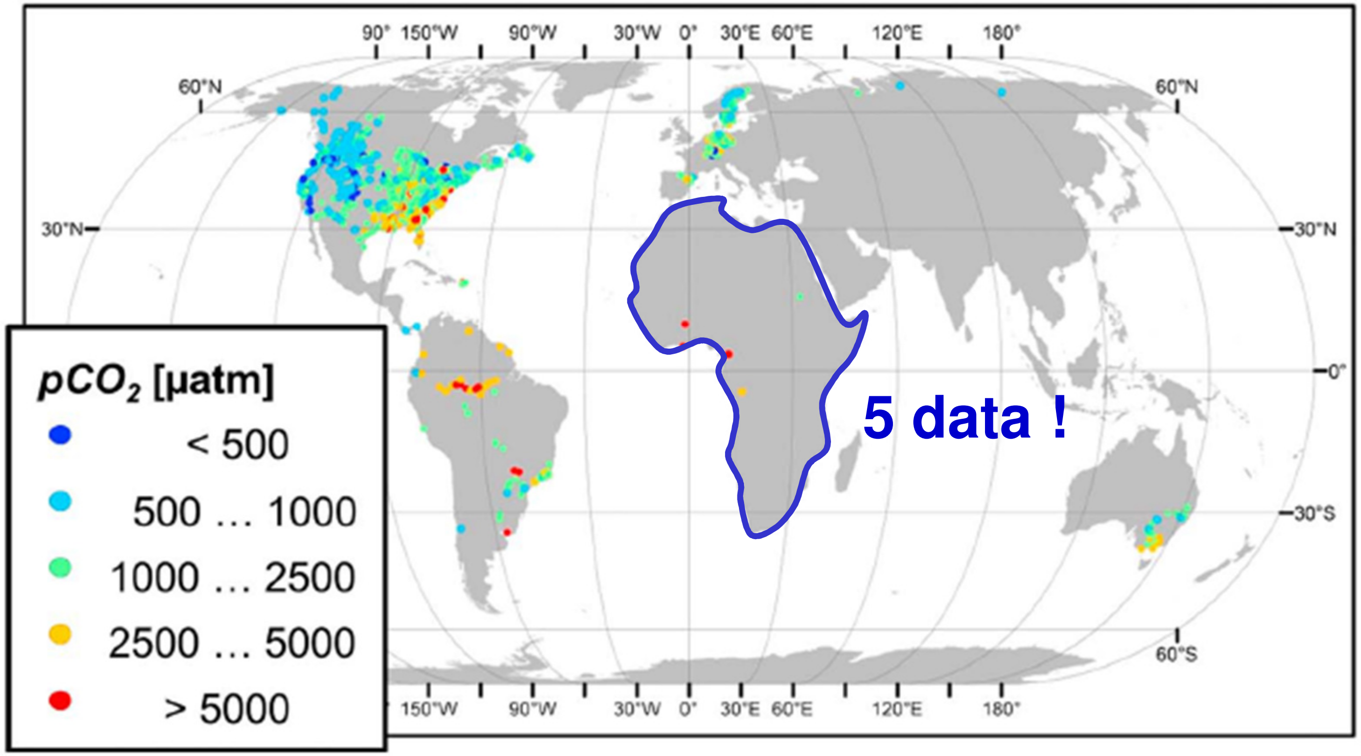


Introduction

Raymond et al. (2013)



Lauerwald et al. (2015)



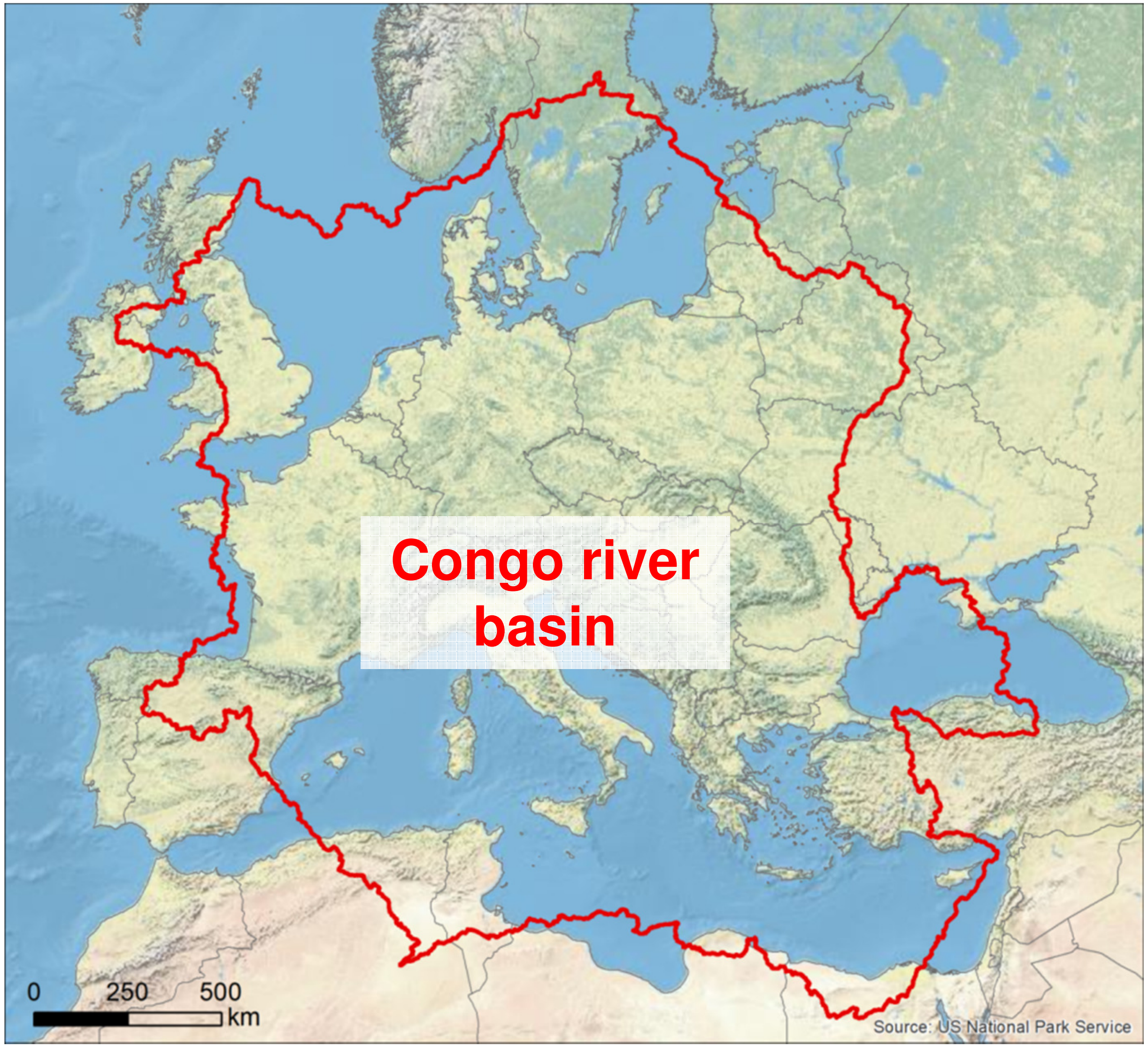
Introduction

Tropical Rivers:

- **Highest CO_2 emissions**
- **Lowest data coverage**
- **(Lowest confidence in CO_2 data quality)**

Congo river

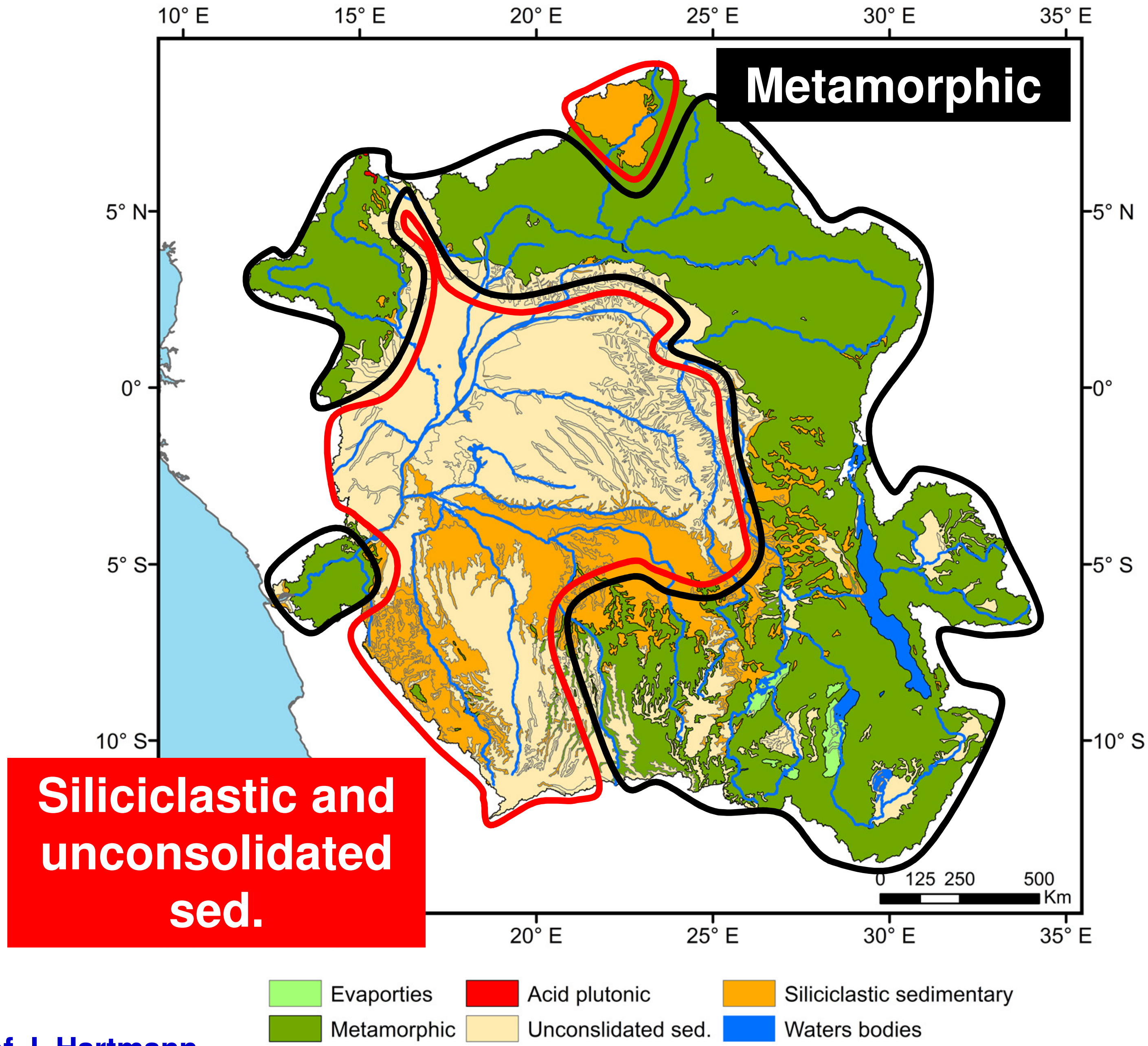
Congo


Congo river basin
0 250 500
km
Source: US National Park Service

Congo

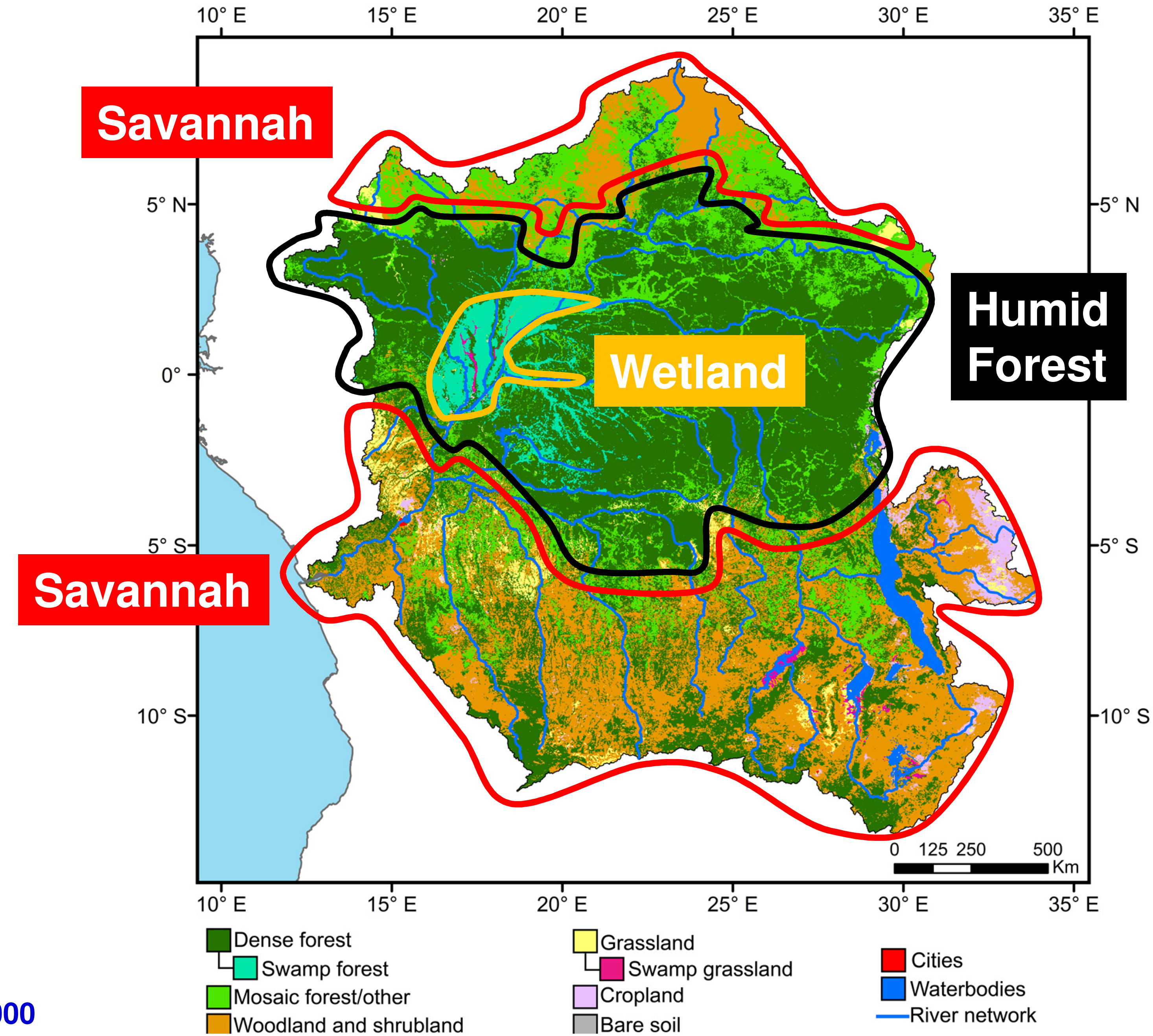

Congo river basin
0 250 500
km
Source: US National Park Service

Congo



Courtesy of J. Hartmann

Congo



GLC 2000


Wetland
= flooded forest
(Tributary)


Wetland
= floating macrophytes
(Tributary)

Wetland
= floating macrophytes
(Congo mainstem)

Congo

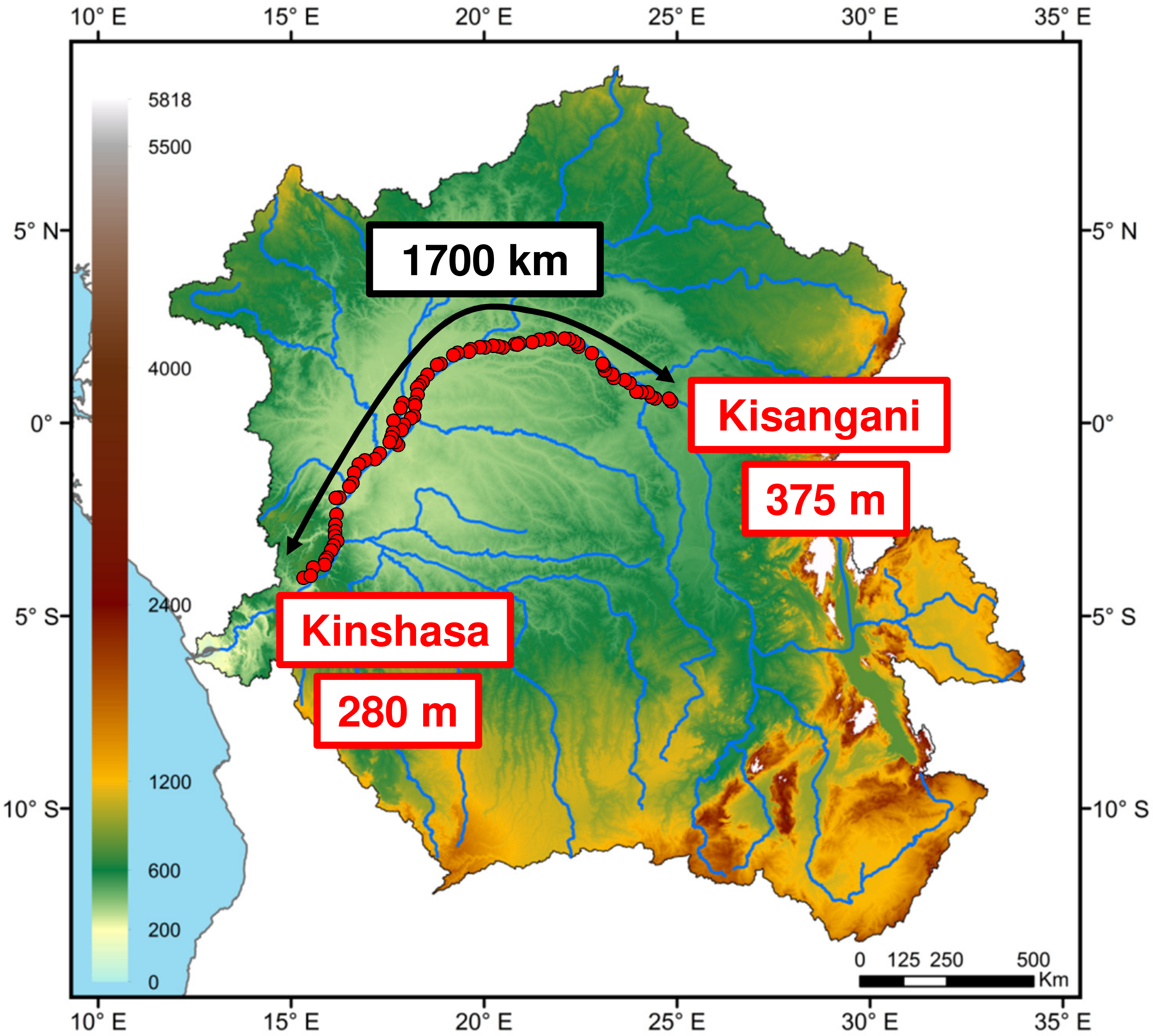
Azolla pinnata

Vossia cuspidata
« Hippo grass »

Eichhornia crassipes
« water hyacinth »

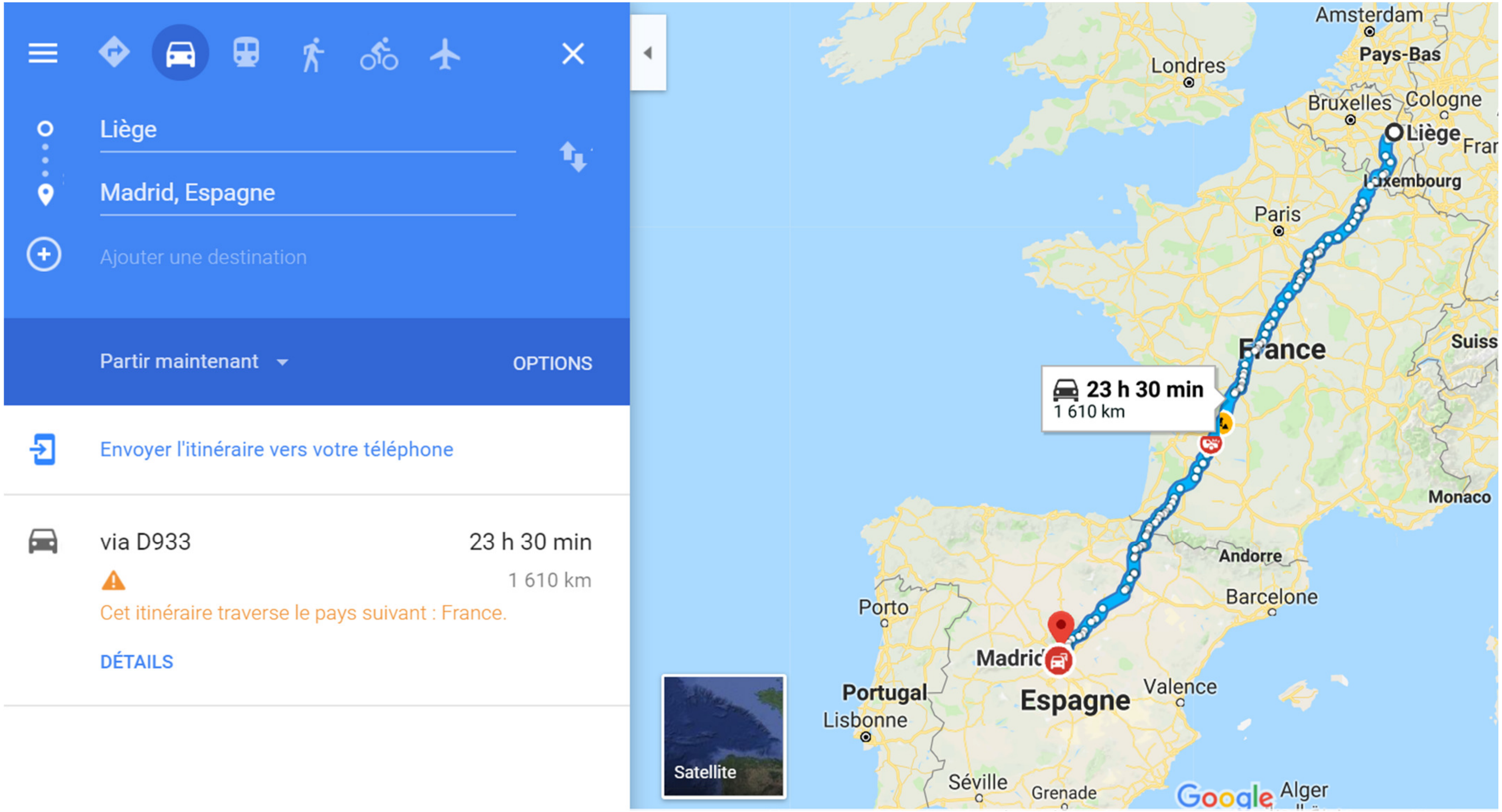
Salvinia auriculata

Congo

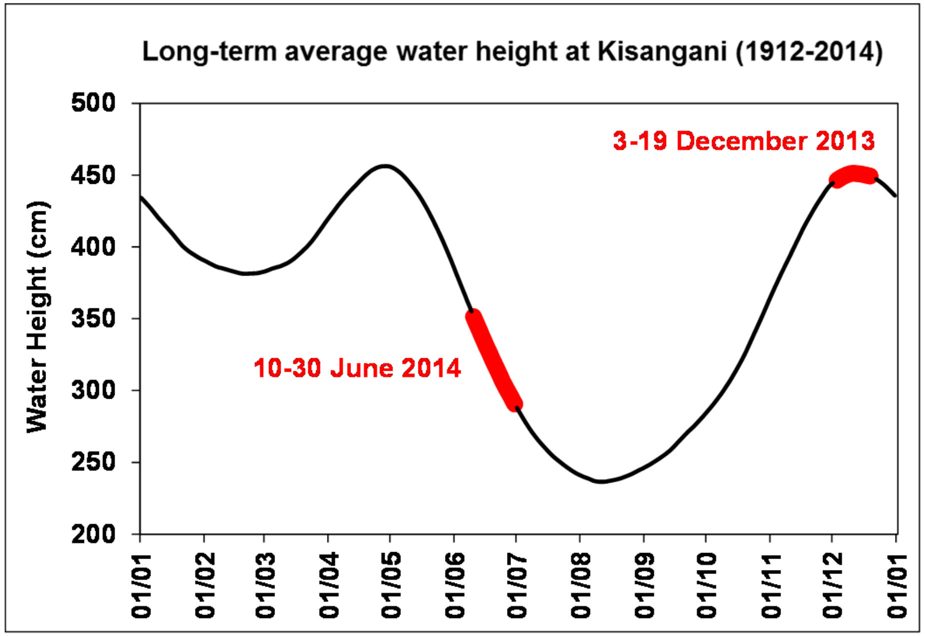


10° E
15° E
20° E
25° E
30° E
35° E
5° N
0°
5° S
10° S
5818
5500
4000
2400
1200
600
200
0
1700 km
Kisangani
375 m
Kinshasa
280 m
0 125 250 500
Km

Congo


Liège
Madrid, Espagne
Ajouter une destination
Partir maintenant
OPTIONS
Envoyer l'itinéraire vers votre téléphone
via D933
23 h 30 min
1 610 km
Cet itinéraire traverse le pays suivant : France.
DÉTAILS
Amsterdam
Pays-Bas
Londres
Bruxelles
Cologne
Liège
Paris
France
Suiss
23 h 30 min
1 610 km
Monaco
Andorre
Barcelone
Porto
Madrid
Portugal
Espagne
Valence
Lisbonne
Satellite
Séville
Grenade
Alger

Cruises & Methods



164 stations
29 variables

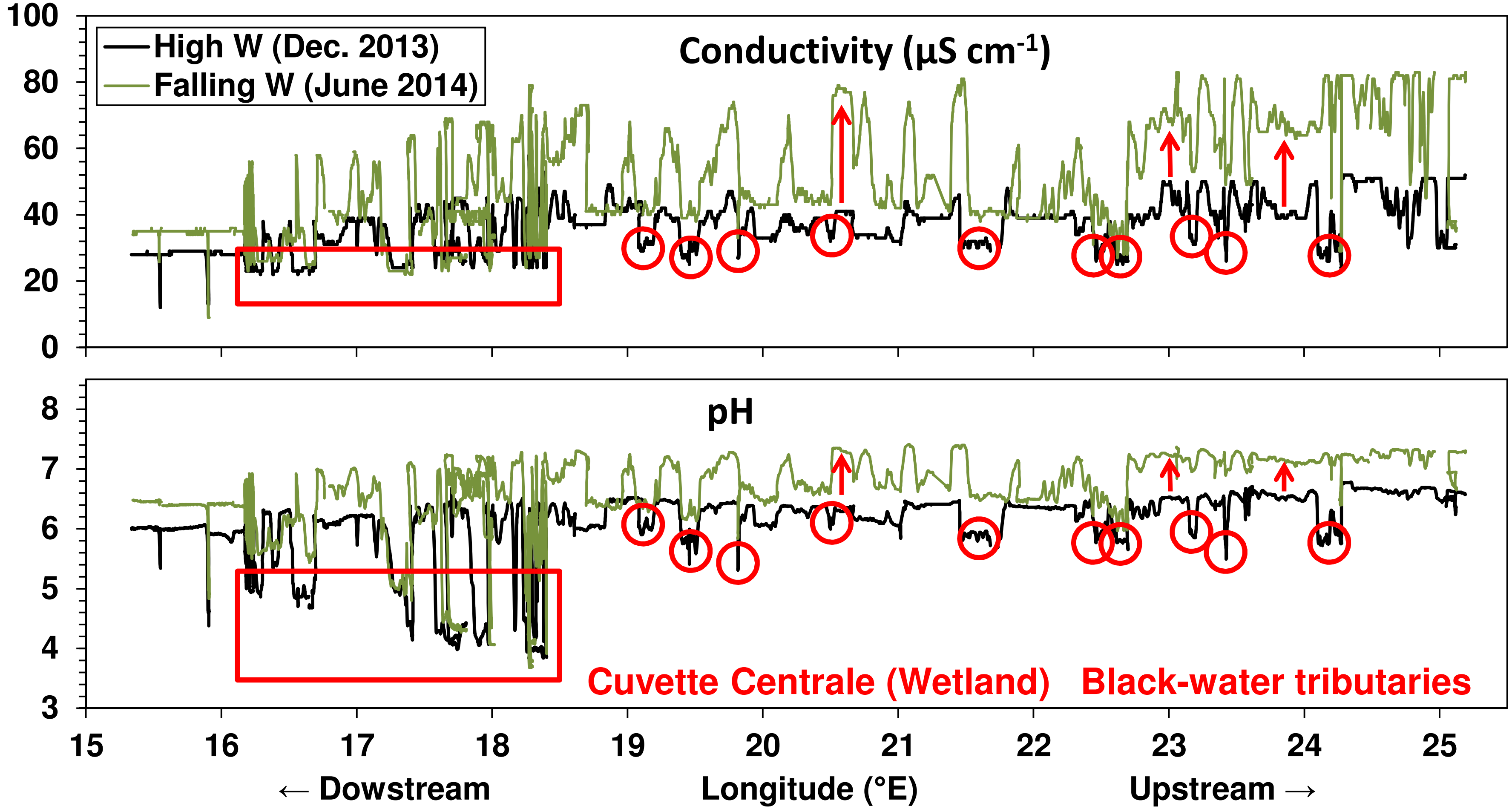
> 23,000 continuous measurements
pCO_2, cond, temp, pH, O_2, TSM, cDOM

Cruises & Methods

Results

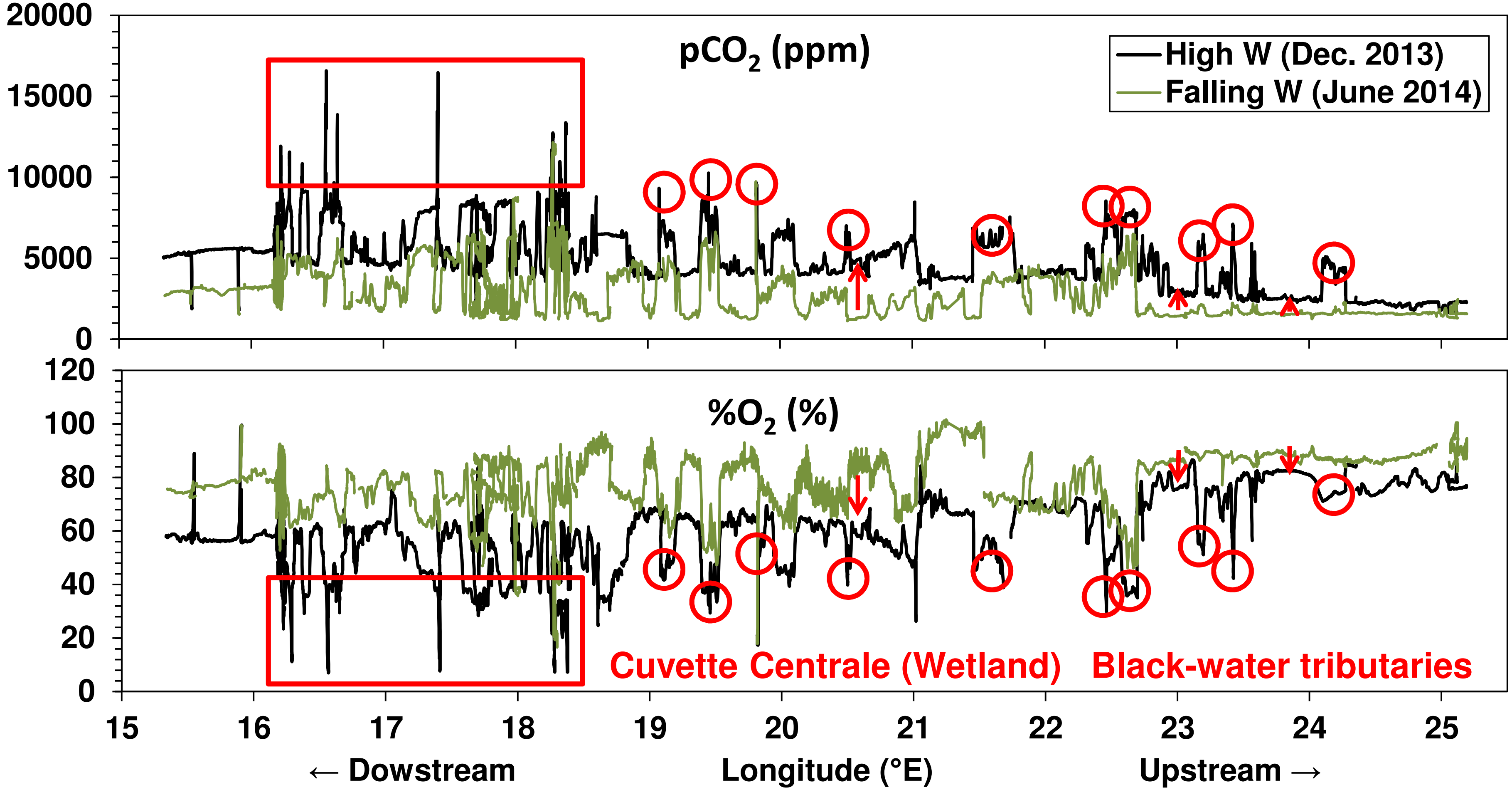
Spatial variations of CO_2

Results

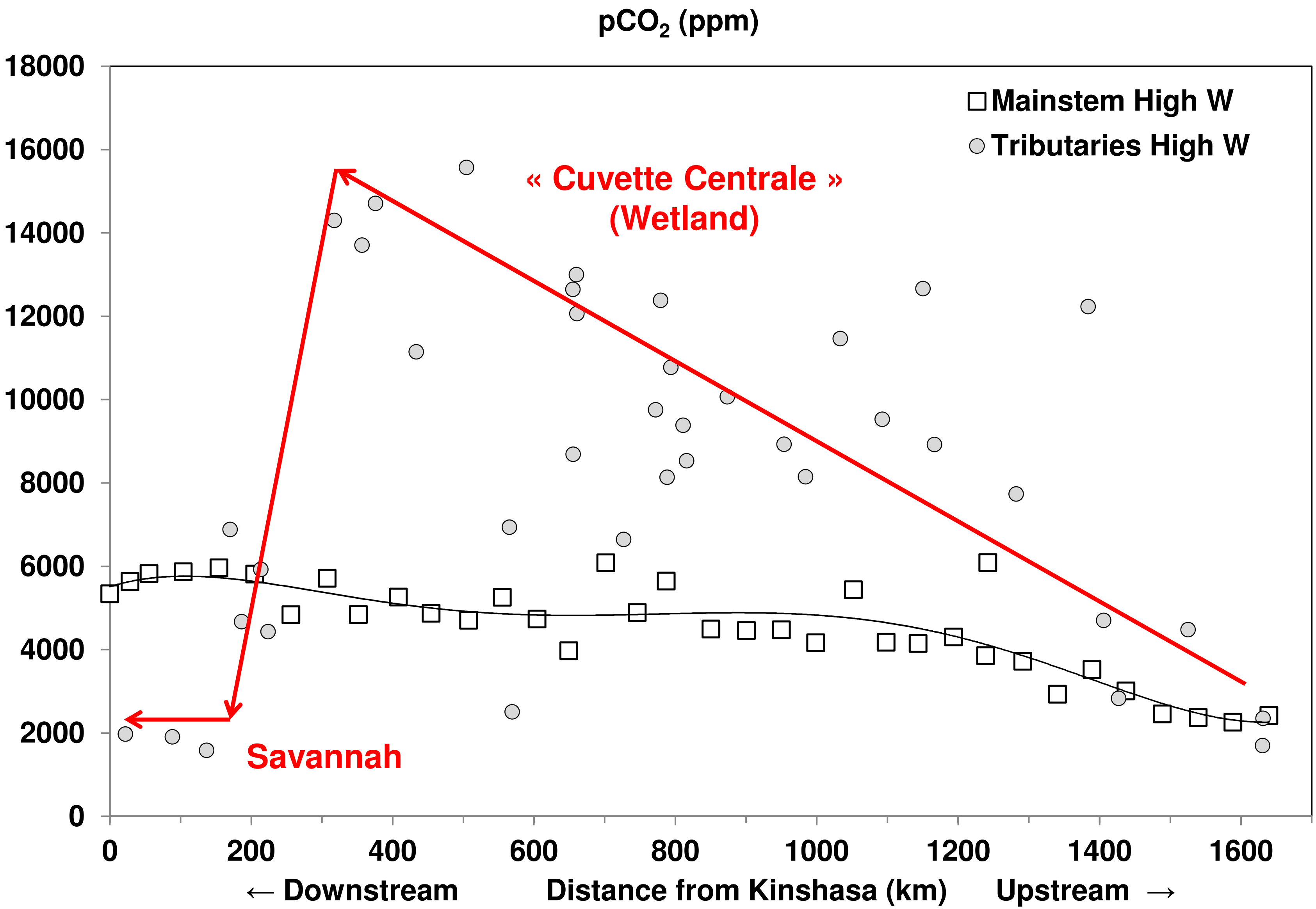


High W (Dec. 2013)
Falling W (June 2014)
Conductivity (µS cm-1)
100
80
60
40
20
0
pH
8
7
6
5
4
3
Cuvette Centrale (Wetland)
Black-water tributaries
15
16
17
18
19
20
21
22
23
24
25
← Dowstream
Longitude (°E)
Upstream →

Results

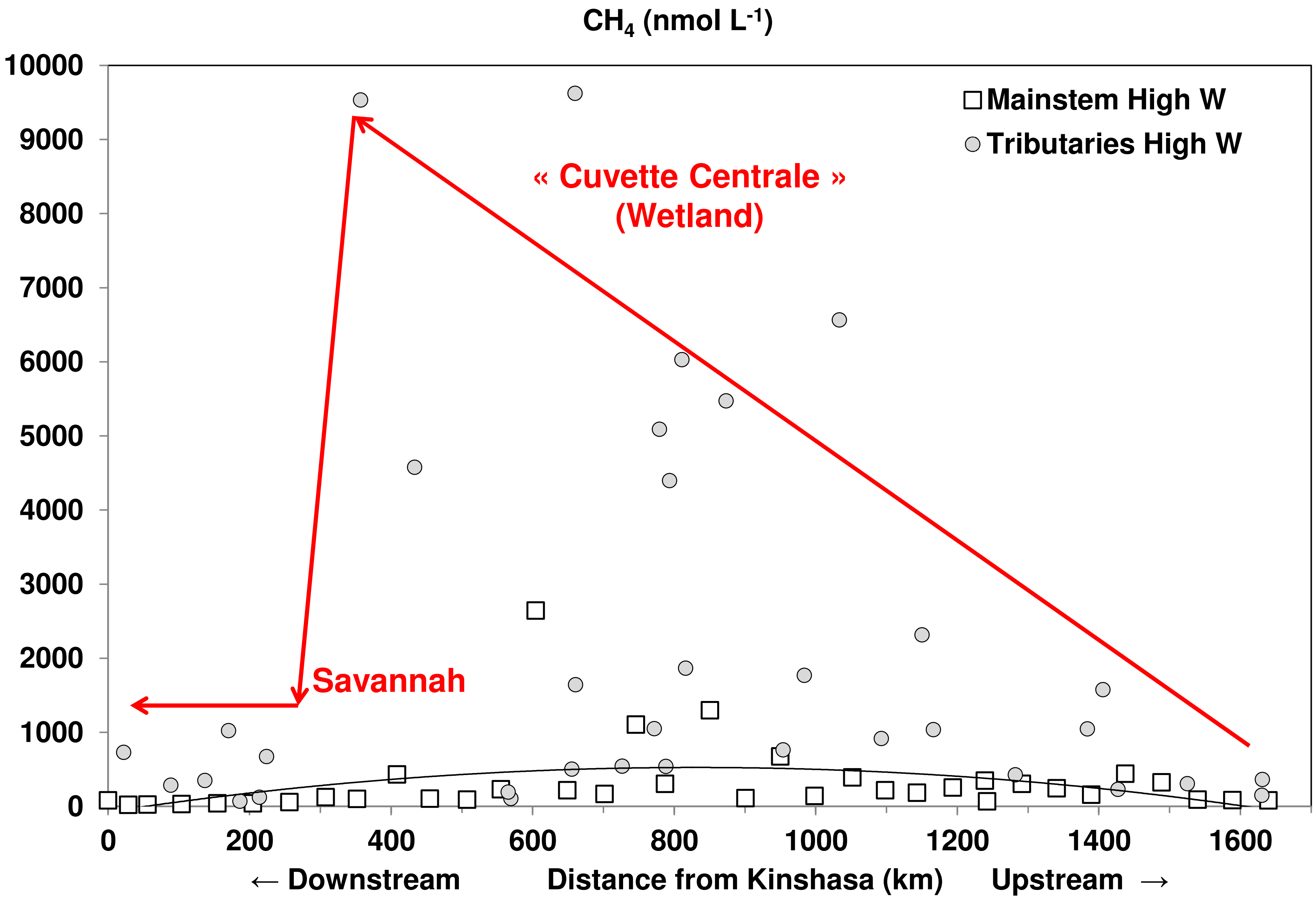

pCO$_2$ (ppm)
High W (Dec. 2013)
Falling W (June 2014)
20000
15000
10000
5000
0
%O$_2$ (%)
120
100
80
60
40
20
0
Cuvette Centrale (Wetland)
Black-water tributaries
15
16
17
18
19
20
21
22
23
24
25
← Dowstream
Longitude (°E)
Upstream →

Results



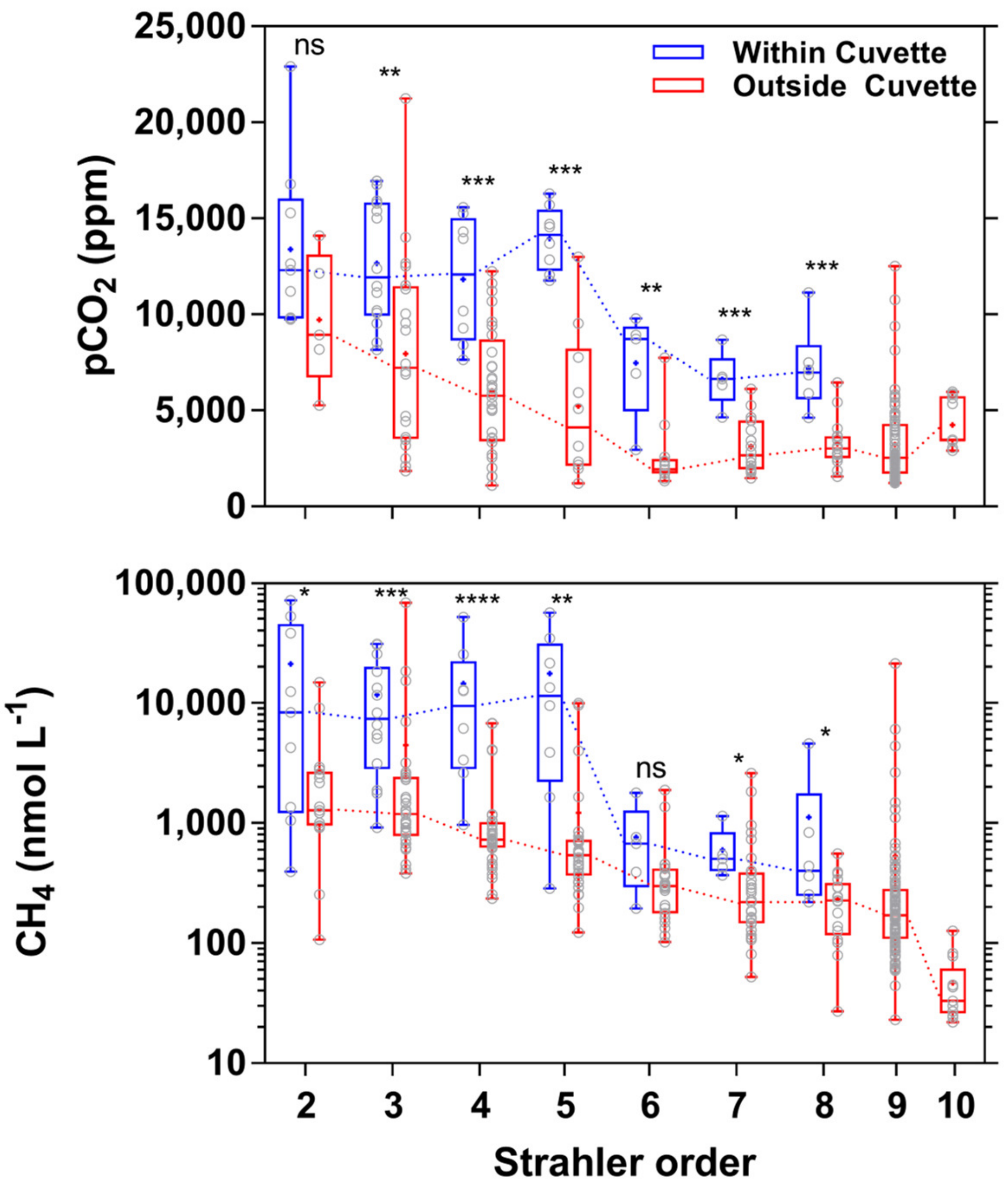
pCO2 (ppm)
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
0
200
400
600
800
1000
1200
1400
1600
← Downstream
Distance from Kinshasa (km)
Upstream →
Mainstem High W
Tributaries High W
« Cuvette Centrale »
(Wetland)
Savannah

Results



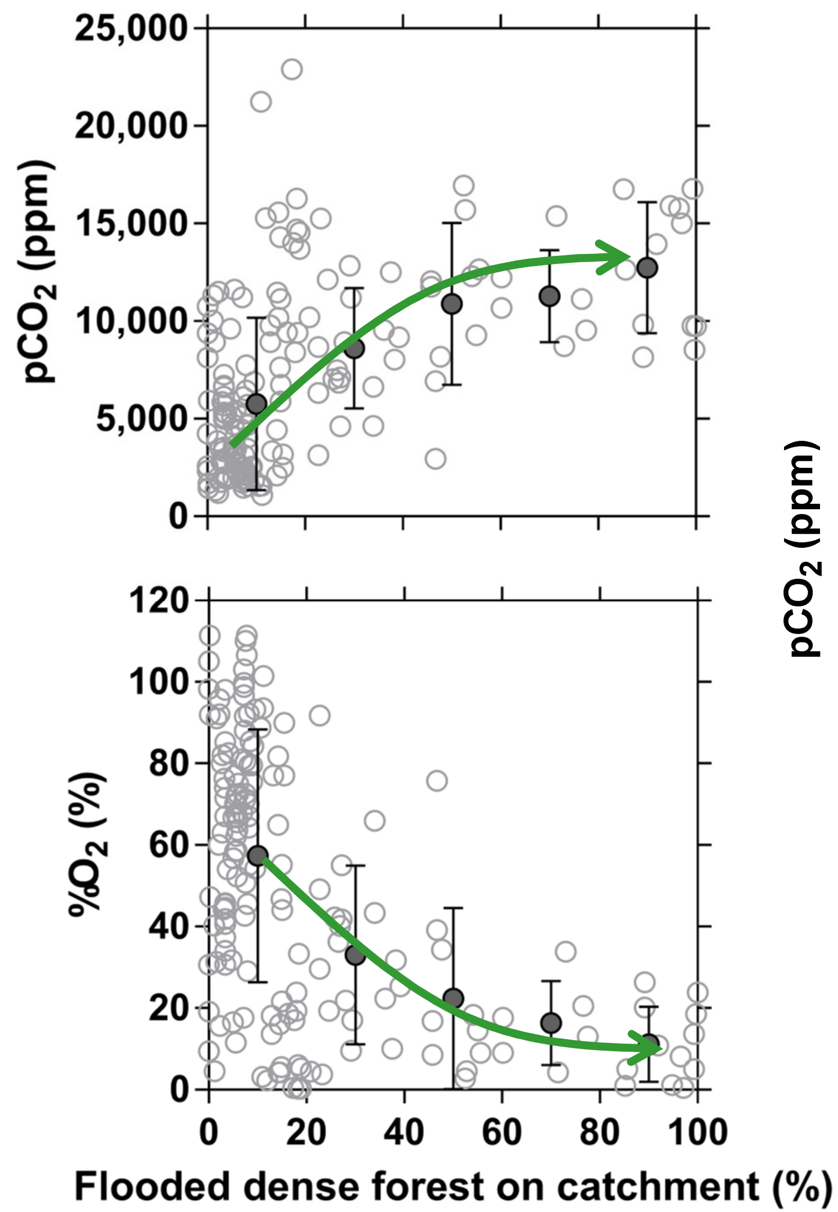
CH4 (nmol L-1)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
200
400
600
800
1000
1200
1400
1600
← Downstream
Distance from Kinshasa (km)
Upstream →
Mainstem High W
Tributaries High W
« Cuvette Centrale »
(Wetland)
Savannah

Results



Within Cuvette
Outside Cuvette
pCO2 (ppm)
25,000
20,000
15,000
10,000
5,000
0
ns
**
***
***
**
***
***
CH4 (nmol L-1)
100,000
10,000
1,000
100
10
*
***
****
**
ns
*
*
2
3
4
5
6
7
8
9
10
Strahler order

Results

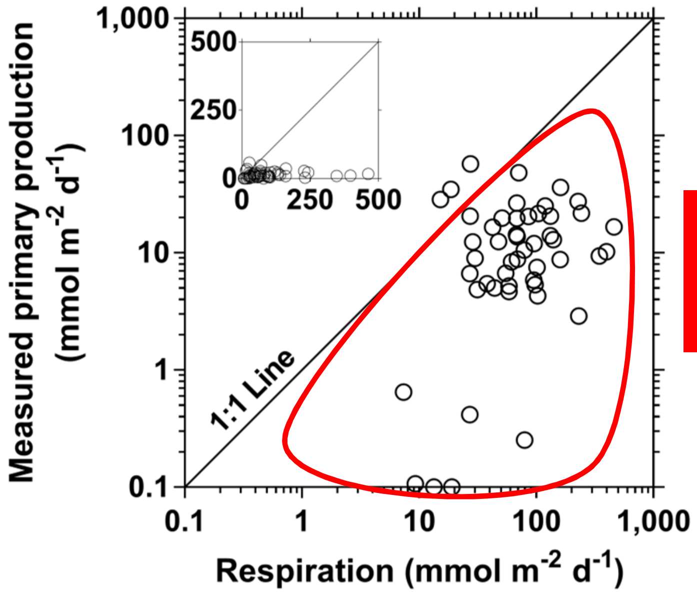


25,000
20,000
15,000
10,000
5,000
0
pCO2 (ppm)
120
100
80
60
40
20
0
%O2 (%)
0 20 40 60 80 100
Flooded dense forest on catchment (%)
25,000
20,000
15,000
10,000
5,000
0
pCO2 (ppm)
0 20 40 60 80 100 120
%O2 (%)

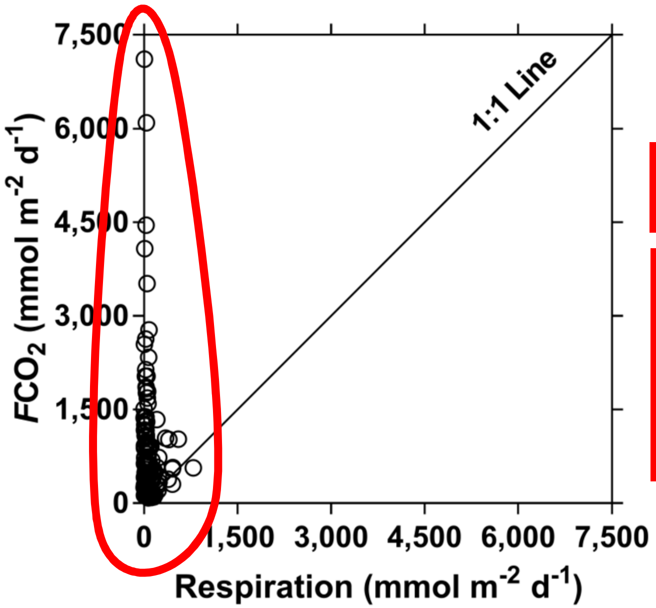
Results

Metabolism versus CO_2 emissions

Results



Net heterotrophic
R >> P



CO_2 emission >> R

Lateral CO_2 inputs
>>
in-stream R

Results

CO_2 and CH_4 in rivers & streams of the Congo seem to be mainly related to wetland inputs

Based on:

- **Spatial patterns (in/out of the Cuvette Centrale)**
- **Metabolic measurements**
- **Stable isotopic composition of DIC (not shown here)**

Results

CO_2 emission from Congo rivers-streams

$FCO_2 = k\, H\, \Delta pCO_2$

- FCO_2 = air-water CO_2 flux
- H = Henry's constant = f(temperature)
- ΔpCO_2 = air-water gradient of pCO_2 (measured)
- k = gas transfer velocity

k = f (flow velocity; slope)

Limnology and Oceanography
FLUIDS & ENVIRONMENTS

ORIGINAL ARTICLE

Scaling the gas transfer velocity and hydraulic geometry in streams and small rivers

Peter A. Raymond,[1] Christopher J. Zappa,[2] David Butman,[1] Thomas L. Bott,[3] Jody Potter,[4] Patrick Mulholland,[5] Andrew E. Laursen,[6] William H. McDowell,[4] and Denis Newbold[3]

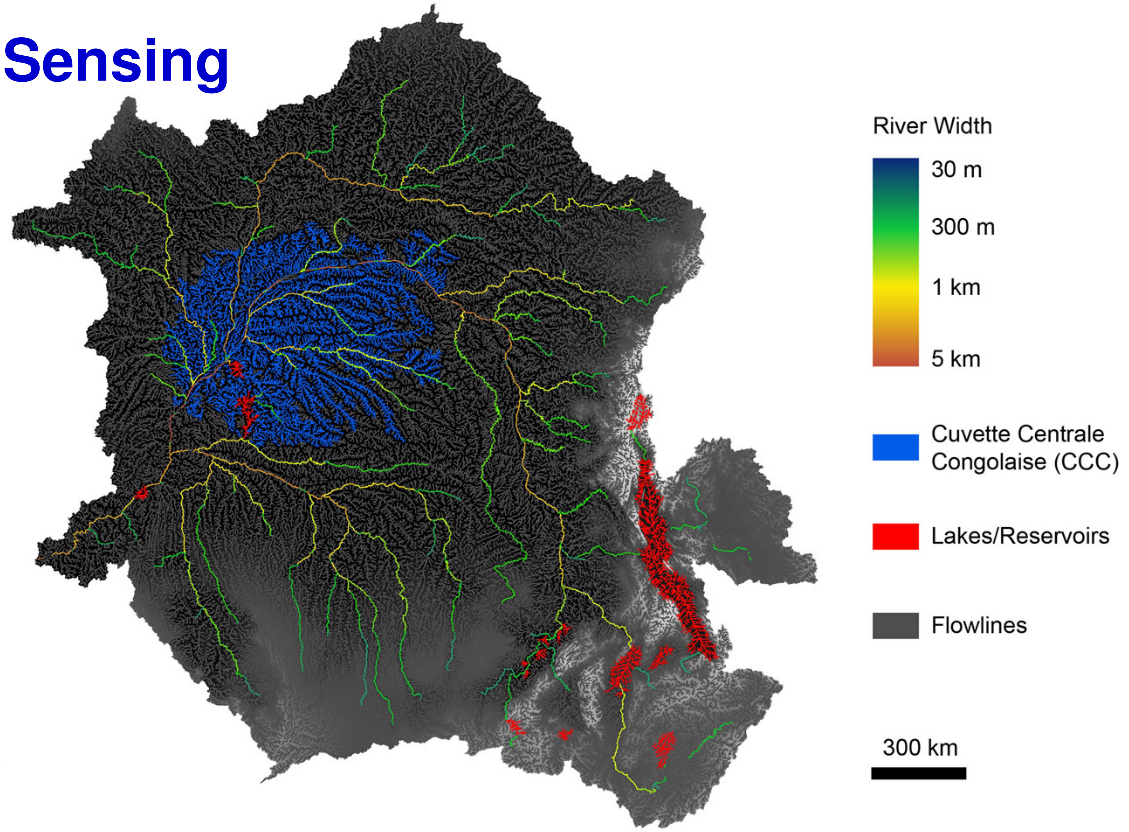
Results

CO_2 emission from Congo rivers-streams

Stream surface area = length x width

length = Hydrosheds

width = Remote Sensing



Science

Global extent of rivers and streams

George H. Allen*† and Tamlin M. Pavelsky

Results

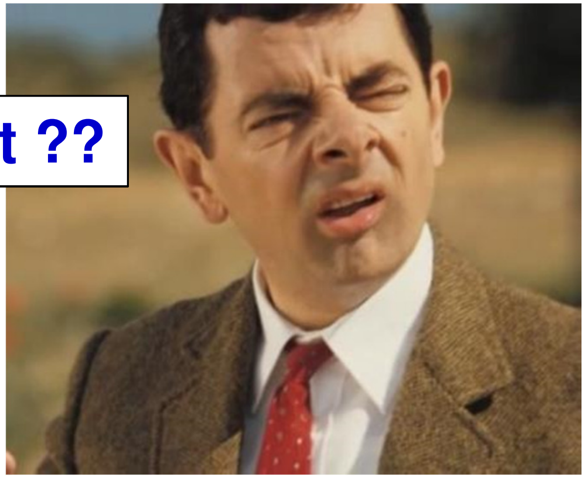
CO_2 emission from Congo rivers-streams
= 251 TgC yr^{-1}

Net ecosystem exchange (NEE) Congo forests + savannahs
= 77 TgC yr^{-1}

CO_2 emission from rivers 3 times higher than terrestrial NEE ???

Export of C from soils to rivers
= 2-3% of NEE
for *terra firme* forests

What ??



Global Change Biology

Global Change Biology (2011) **17**, 1167–1185, doi: 10.1111/j.1365-2486.2010.02282.x

Dissolved carbon leaching from soil is a crucial component of the net ecosystem carbon balance

REIMO KINDLER*‡[1,2], JAN SIEMENS*§[2,3], KLAUS KAISER†, DAVID C. WALMSLEY‡, CHRISTIAN BERNHOFER§, NINA BUCHMANN¶, PIERRE CELLIER||, WERNER EUGSTER¶, GERD GLEIXNER**, THOMAS GRÜNWALD§, ALEXANDER HEIM††, ANDREAS IBROM‡‡, STEPHANIE K. JONES§§, MIKE JONES¶¶, KATJA KLUMPP|||, WERNER KUTSCH***, KLAUS STEENBERG LARSEN‡‡, SIMON LEHUGER||, BENJAMIN LOUBET||, REBECCA MCKENZIE†††, EDDY MOORS‡‡‡, BRUCE OSBORNE‡, KIM PILEGAARD‡‡, CORINNA REBMANN§§§, MATTHEW SAUNDERS‡, MICHAEL W. I. SCHMIDT††, MARION SCHRUMPF**, JANINE SEYFFERTH**, UTE SKIBA§§, JEAN-FRANCOIS SOUSSANA|||, MARK A. SUTTON§§, CINDY TEFS**, BERNHARD VOWINCKEL§, MATTHIAS J. ZEEMAN¶ and MARTIN KAUPENJOHANN*

Results

CO_2 emission from Congo rivers-streams
= 251 TgC yr^{-1}

Mostly sustained by C leaked from wetlands ?

Export C from flooded forest in Amazon (Abril et al.)

+

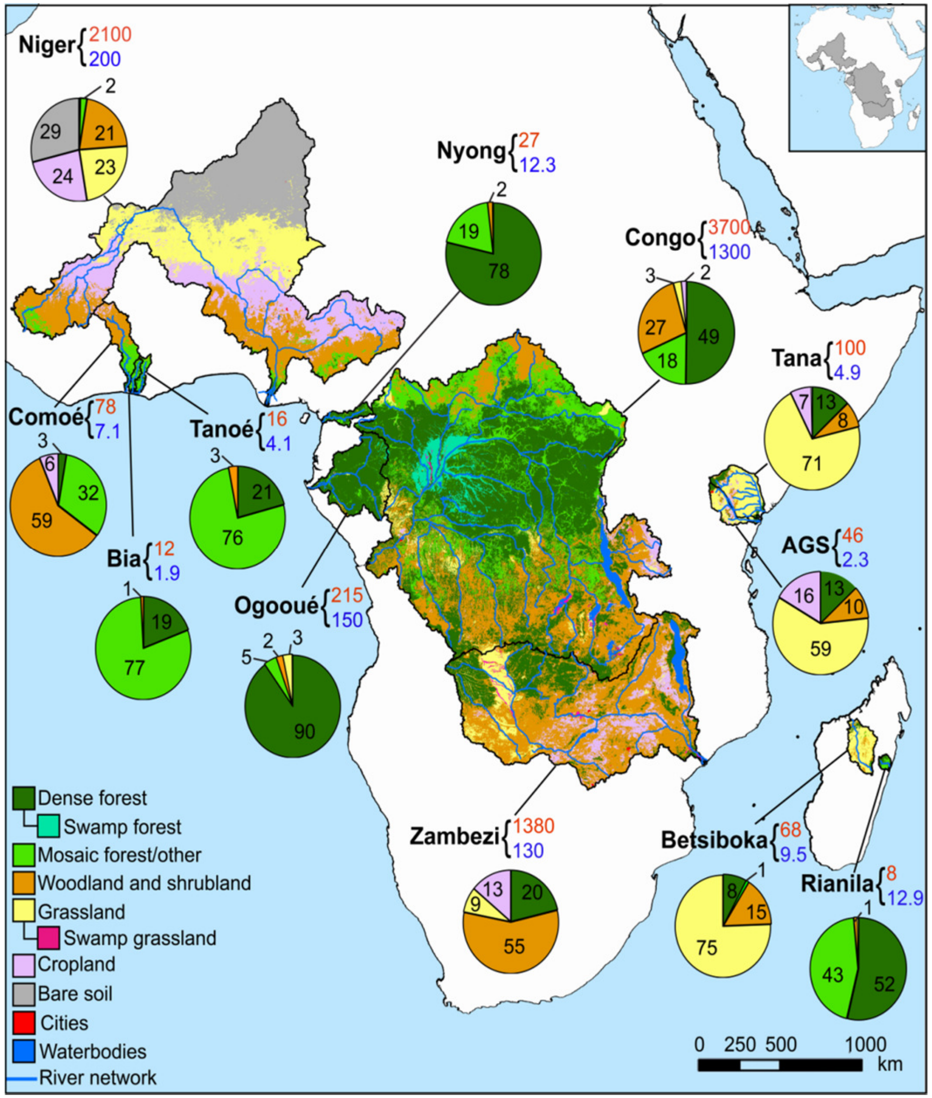
Surface of flooded forest in Congo

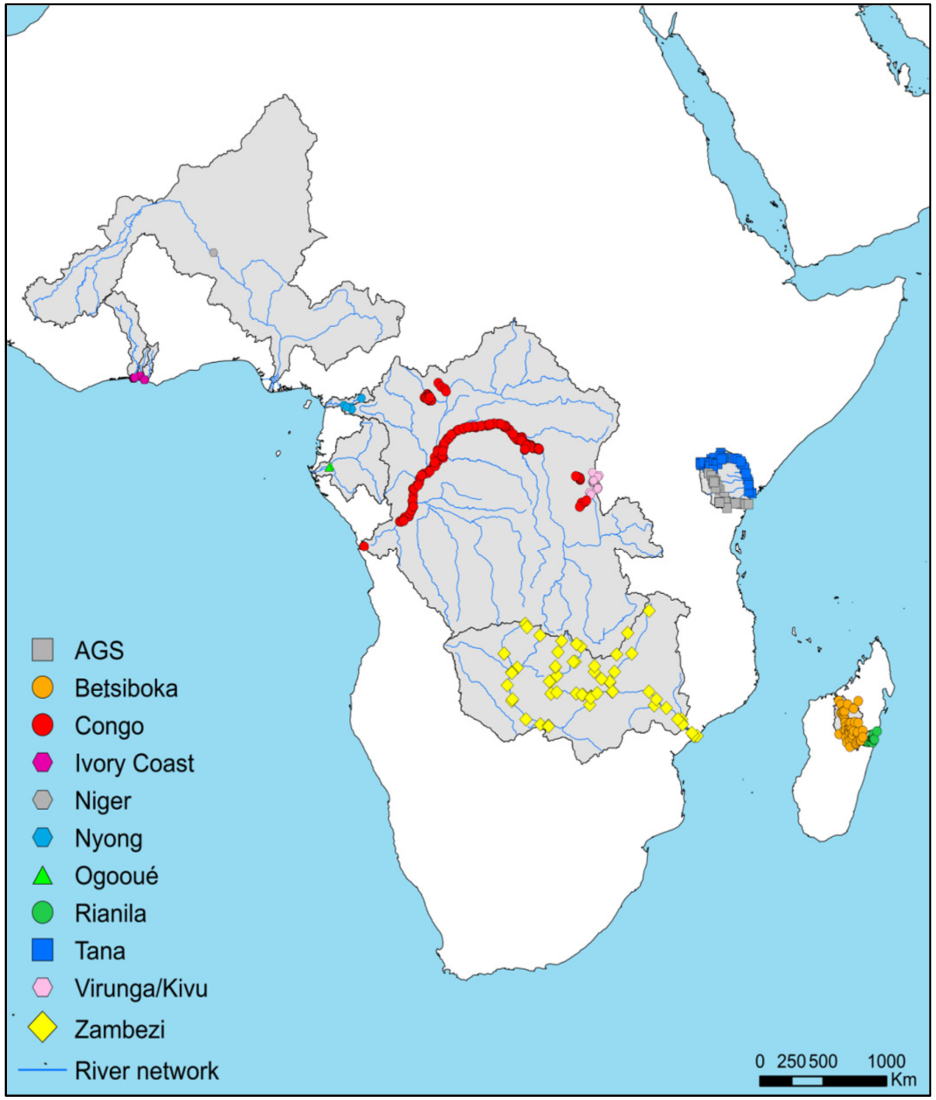
C leaked from wetlands = 400 TgC yr^{-1}

Results

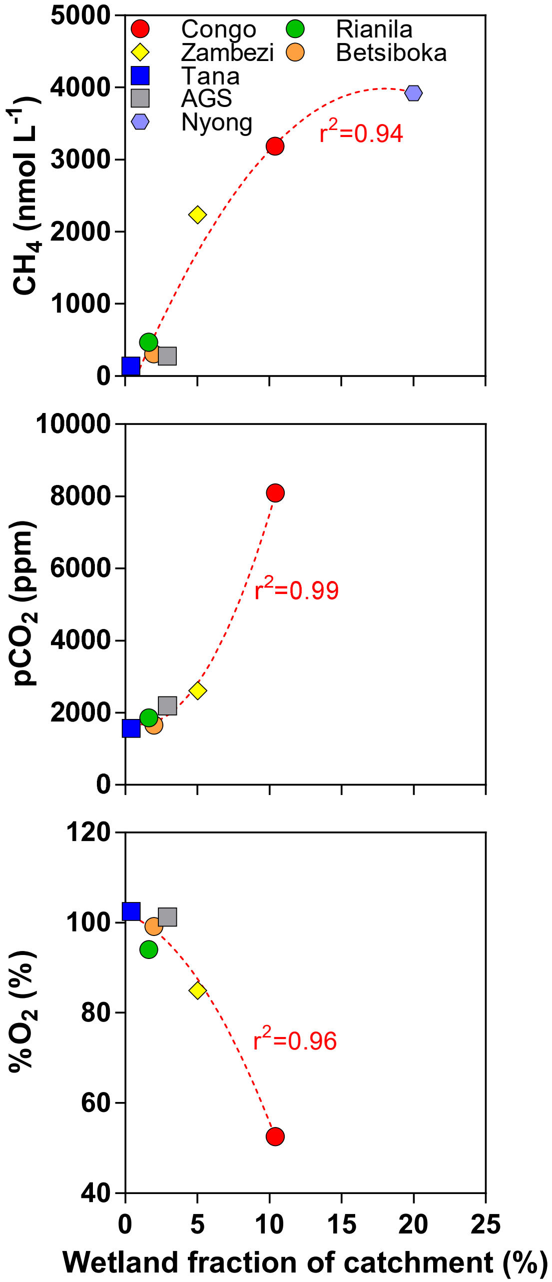
Congo & other African rivers

Results


Niger 2100 200
29 21 23 24 2
Nyong 27 12.3
19 78 2
Congo 3700 1300
3 2 27 49 18
Tana 100 4.9
7 13 8 71
Comoé 78 7.1
3 6 32 59
Tanoé 16 4.1
3 21 76
Bia 12 1.9
1 19 77
Ogooué 215 150
5 2 3 90
AGS 46 2.3
16 13 10 59
Zambezi 1380 130
13 20 9 55
Betsiboka 68 9.5
1 8 15 75
Rianila 8 12.9
1 43 52
Dense forest
Swamp forest
Mosaic forest/other
Woodland and shrubland
Grassland
Swamp grassland
Cropland
Bare soil
Cities
Waterbodies
River network
0 250 500 1000 km


AGS
Betsiboka
Congo
Ivory Coast
Niger
Nyong
Ogooué
Rianila
Tana
Virunga/Kivu
Zambezi
River network
0 250 500 1000 Km

Results



Congo
Rianila
Zambezi
Betsiboka
Tana
AGS
Nyong
CH4 (nmol L-1)
r2=0.94
pCO2 (ppm)
r2=0.99
%O2 (%)
r2=0.96
Wetland fraction of catchment (%)

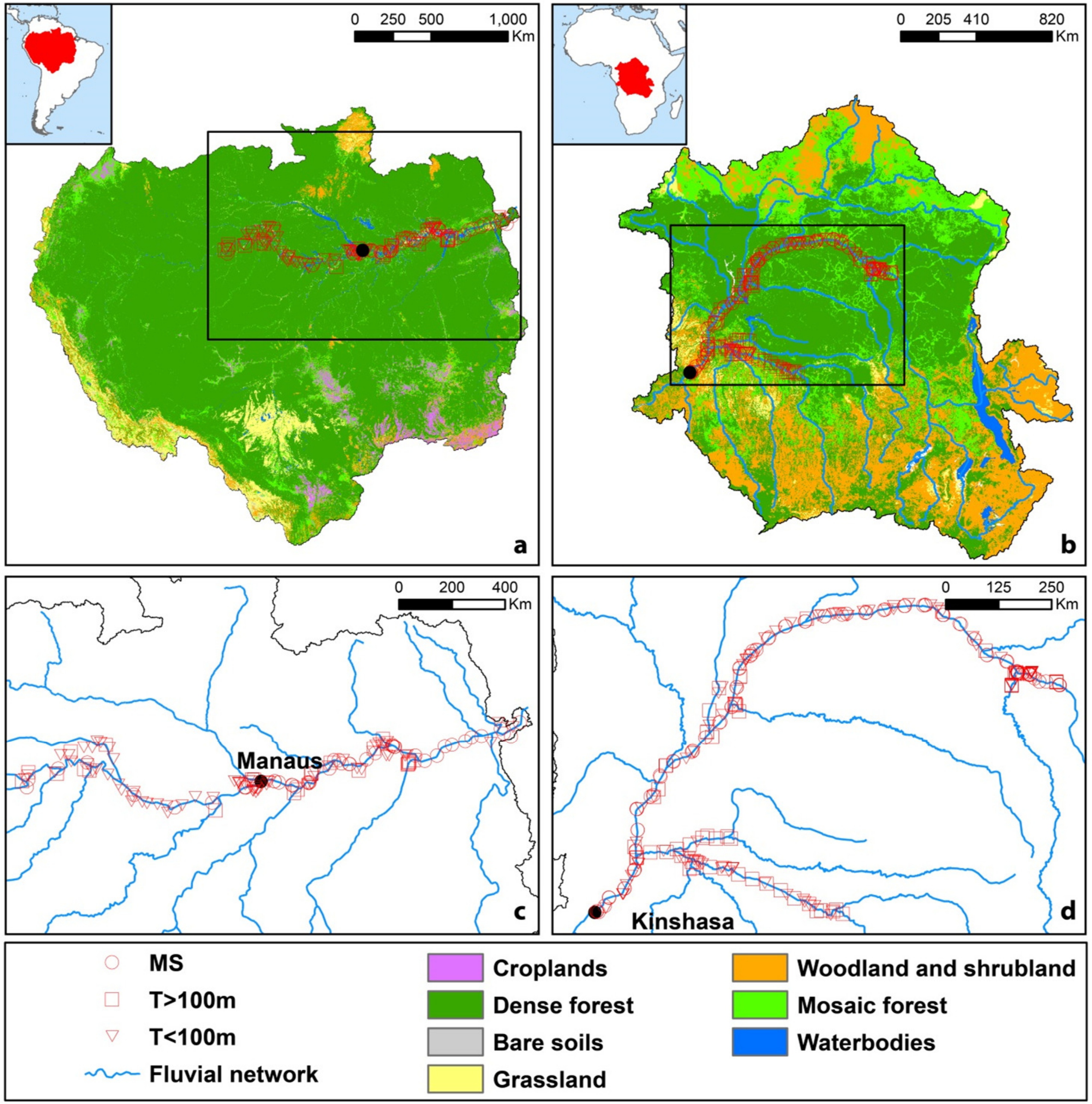
Results

Congo versus Amazon

Results

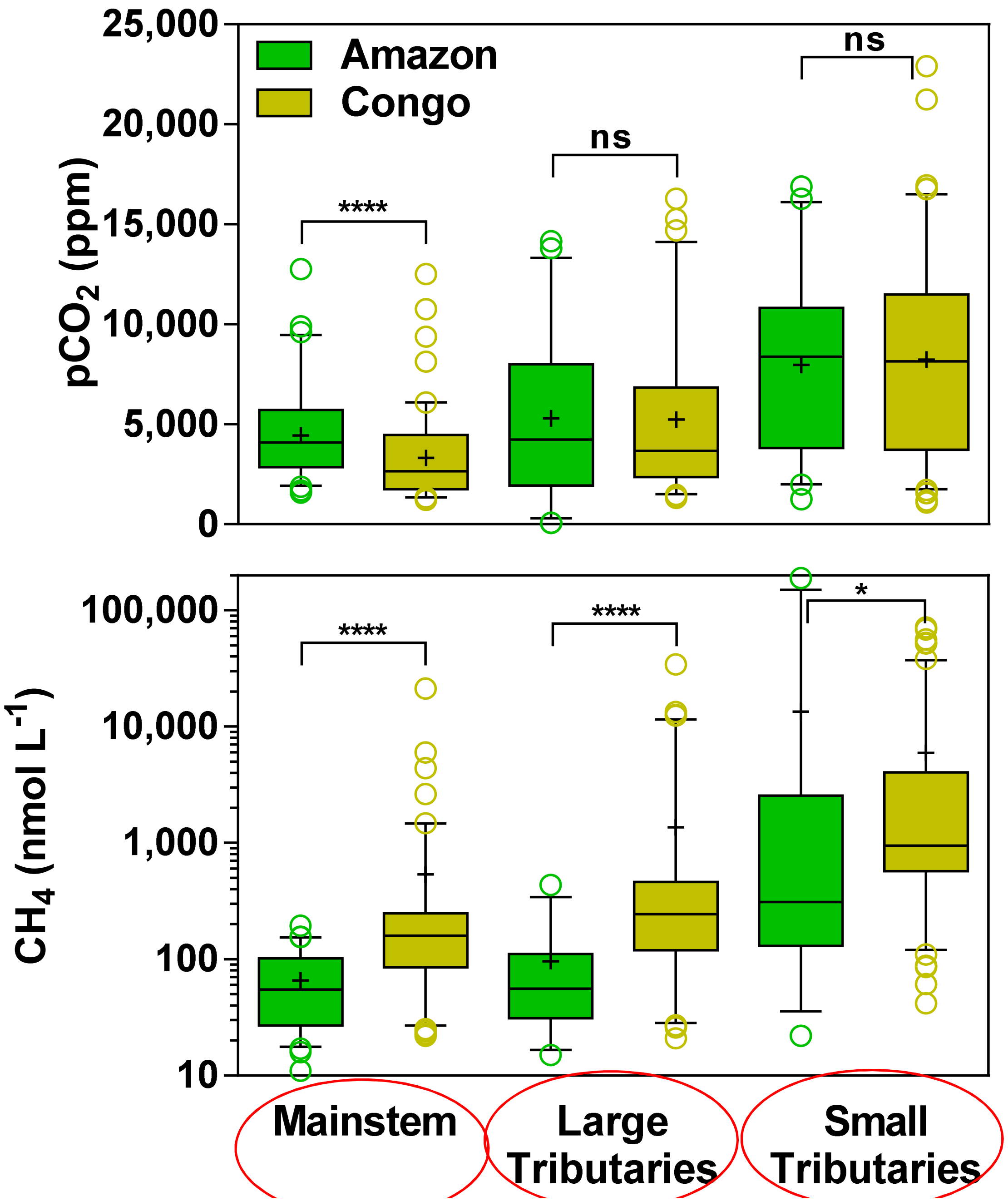
	Amazon		Congo
Catchment area (km^2)	6,025,735	>	3,705,222
Slope (°)	1.4		0.6
Discharge (km^3 yr^{-1})	5,444		1,270
Specific discharge (L s^{-1} km^{-2})	29	>	11
Precipitation (mm)	2,147	>	1,527
Air temperature (°C)	24.6		23.7
River-stream surface area (km^2)	74,904		26,517
Wetland surface area (%)	14		10
Above ground biomass (Mg km^{-2})	909	>	748
Land cover			
Dense Forest (%)	83	>	49
Mosaic Forest (%)	4		18
Woodland and shrubland (%)	4	<	27
Grassland (%)	5		3
Cropland/Bare soil (%)	4		2

Results



0 250 500 1,000 Km
a
0 205 410 820 Km
b
0 200 400 Km
Manaus
c
0 125 250 Km
Kinshasa
d
MS
T>100m
T<100m
Fluvial network
Croplands
Dense forest
Bare soils
Grassland
Woodland and shrubland
Mosaic forest
Waterbodies

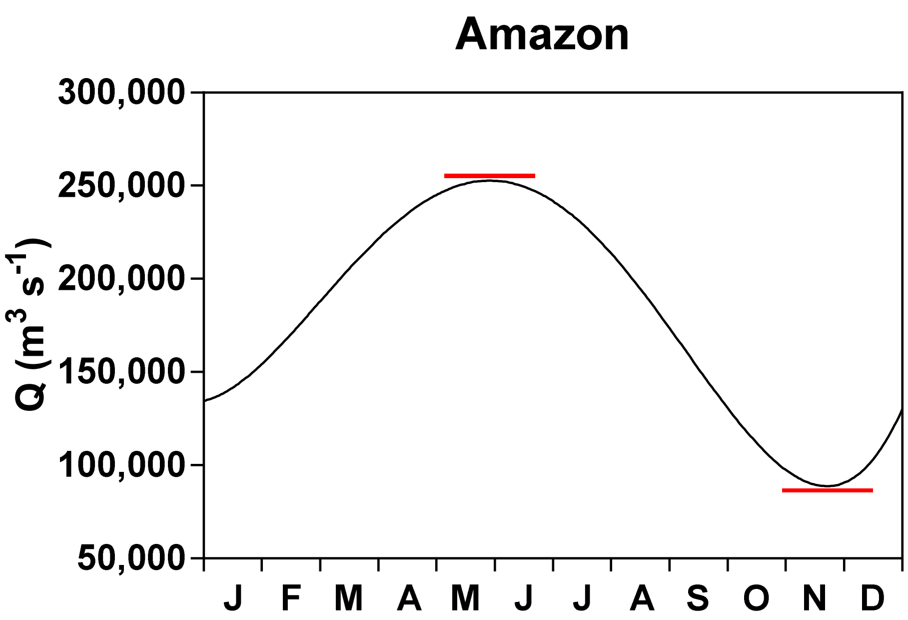
Results

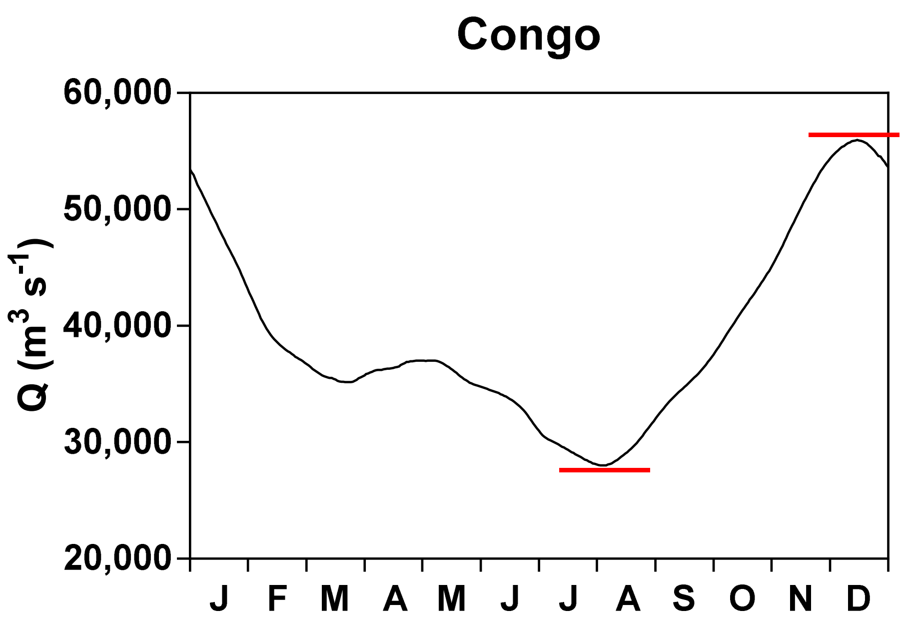


pCO_2 is ± similar

CH_4 is 3-4 times higher in Congo

Results





$Q_{max}:Q_{min} = 2.85$

$H_{max} - H_{min} = 10\text{-}12$ m

Wetlands only in floodplains
Not in river channels

$Q_{max}:Q_{min} = 1.99$

$H_{max} - H_{min} = 3\text{-}4$ m

Wetlands in river channels
$\longrightarrow$ higher CH_4

Further Reading

Biogeosciences, 16, 3801–3834, 2019

Variations in dissolved greenhouse gases (CO_2, CH_4, N_2O) in the Congo River network overwhelmingly driven by fluvial-wetland connectivity

Alberto V. Borges[1], François Darchambeau[1,a], Thibault Lambert[1,b], Cédric Morana[2], George H. Allen[3], Ernest Tambwe[4], Alfred Toengaho Sembaito[4], Taylor Mambo[4], José Nlandu Wabakhangazi[5], Jean-Pierre Descy[1], Cristian R. Teodoru[2,c], and Steven Bouillon[2]

Further Reading

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]

SCIENTIFIC REPORTS

OPEN

Divergent biophysical controls of aquatic CO_2 and CH_4 in the World's two largest rivers

Received: 07 July 2015
Accepted: 29 September 2015
Published: 23 October 2015

Alberto V. Borges[1], Gwenaël Abril[2,3], François Darchambeau[1], Cristian R. Teodoru[4], Jonathan Deborde[2], Luciana O. Vidal[5], Thibault Lambert[1] & Steven Bouillon[4]

Acknowledgments

erc European Research Council

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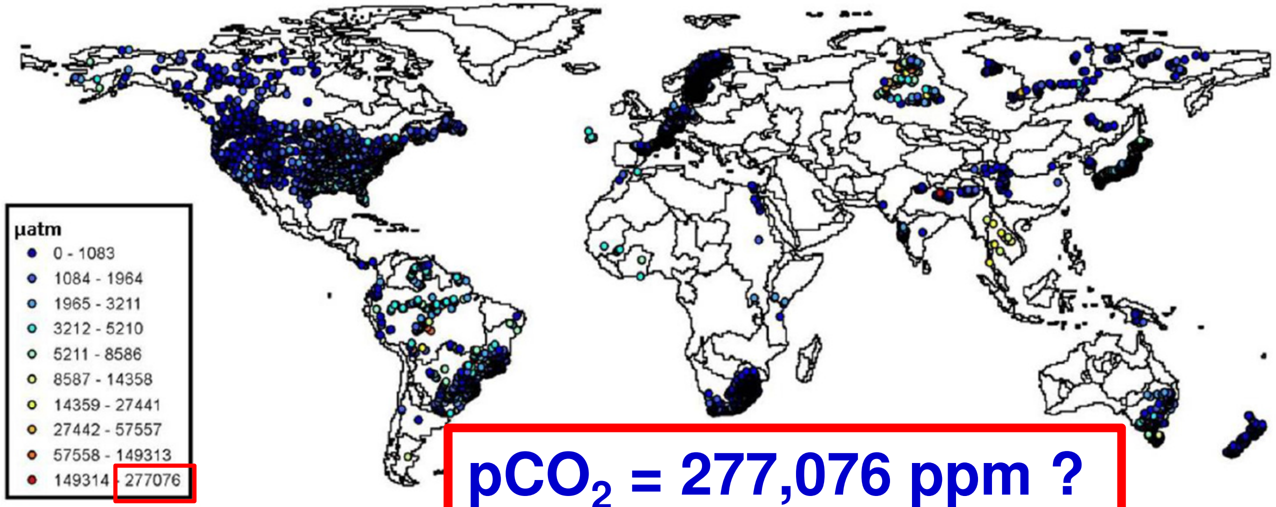
Belgian Science Policy Office belspo



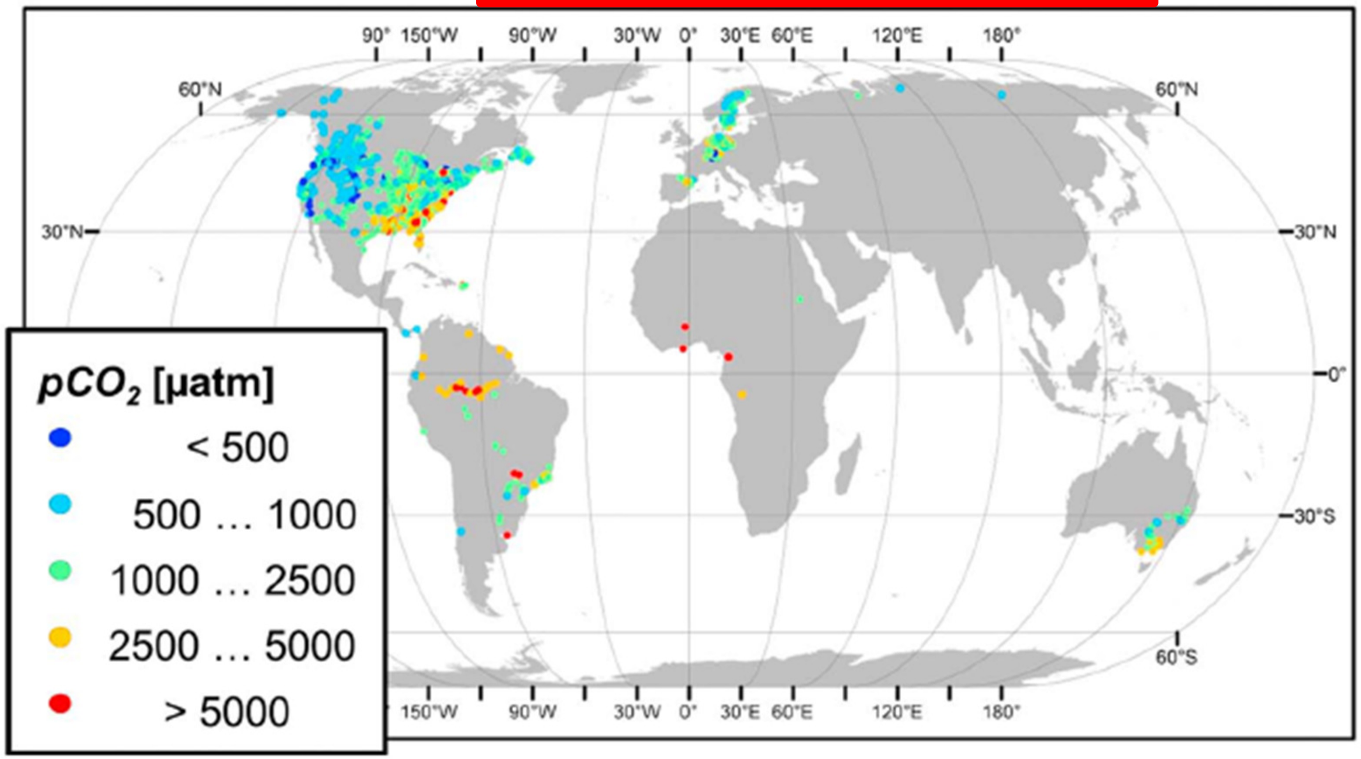

Introduction

Raymond et al. (2013)



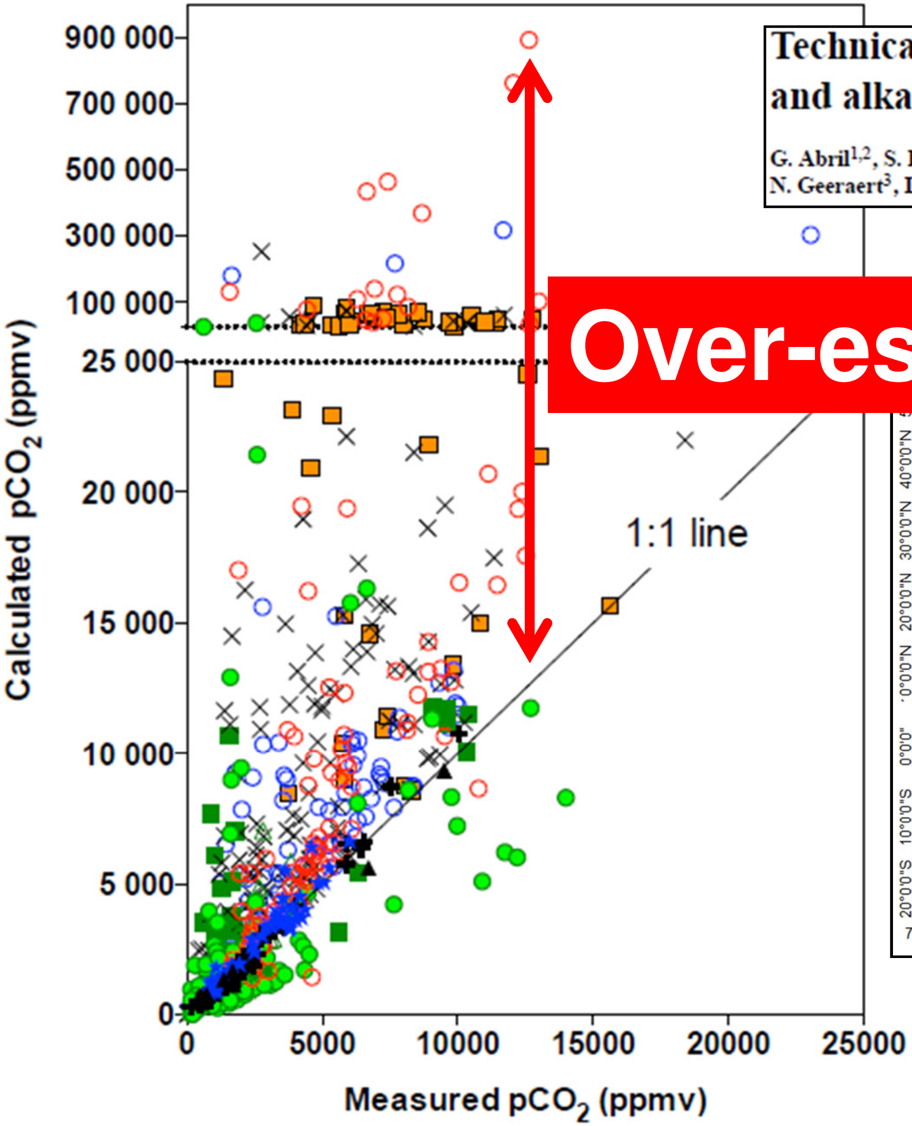
pCO_2 = 277,076 ppm ?

Lauerwald et al. (2015)



Introduction

Raymond et al. (2013) & Lauerwald et al. (2015) used pCO_2 computed from pH and total alkalinity



Technical Note: Large overestimation of pCO_2 calculated from pH and alkalinity in acidic, organic-rich freshwaters

G. Abril[1,2], S. Bouillon[3], F. Darchambeau[4], C. R. Teodoru[3], T. R. Marwick[3], F. Tamooh[3], F. Ochieng Omengo[3], N. Geeraert[3], L. Deirmendjian[1], P. Polsenaere[1], and A. V. Borges[4]

Over-estimation up to 75 x