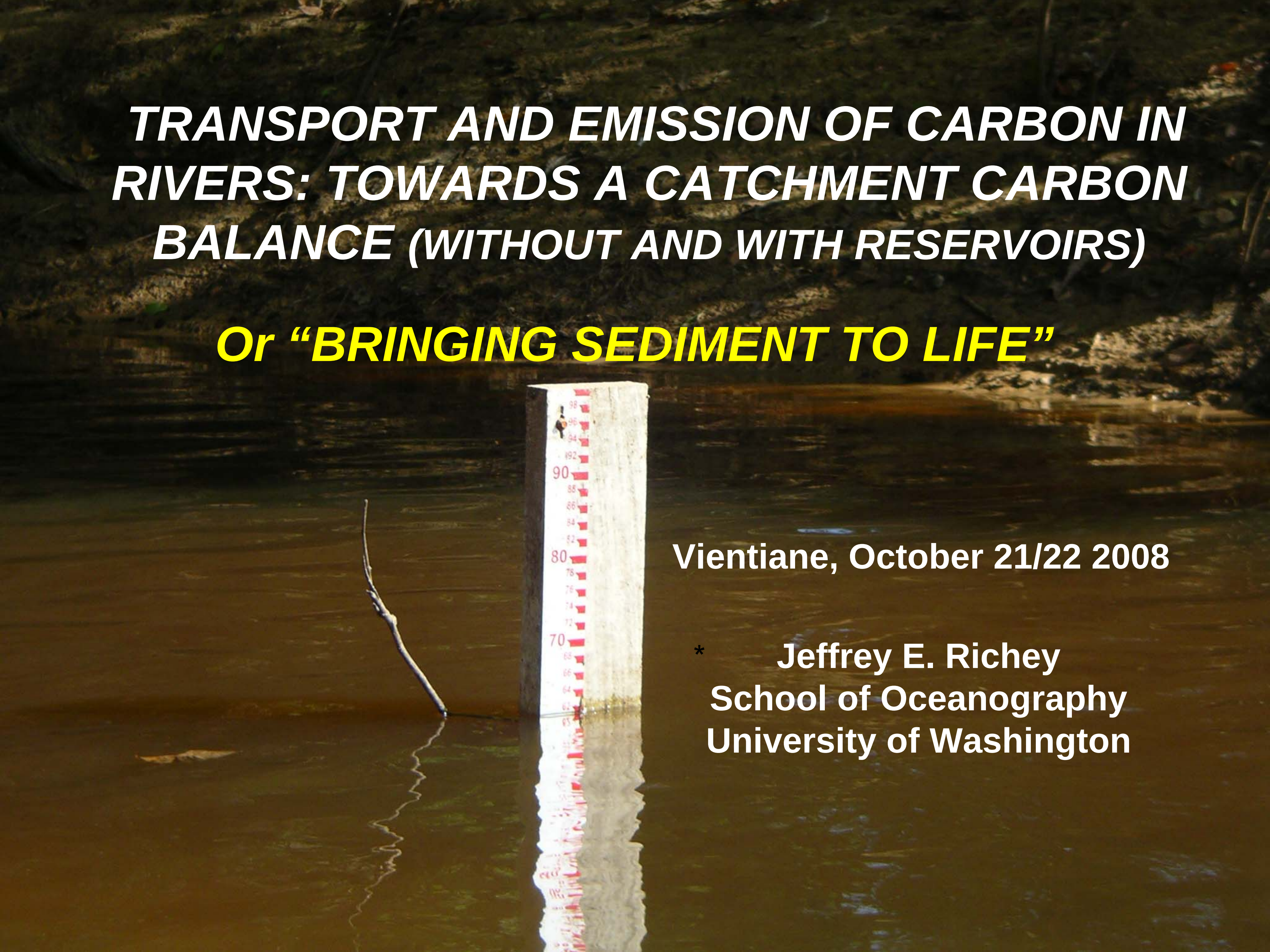
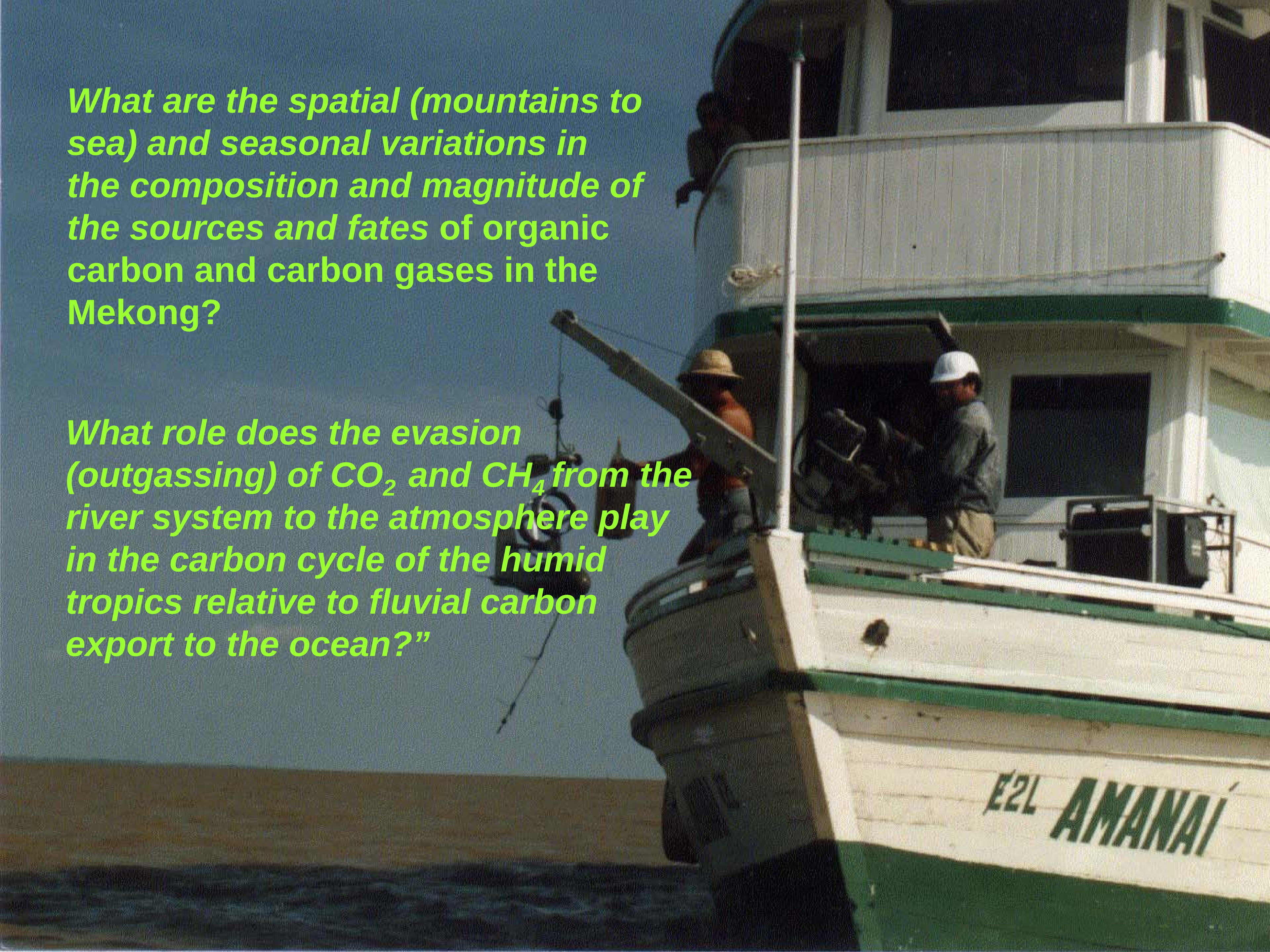


TRANSPORT AND EMISSION OF CARBON IN RIVERS: TOWARDS A CATCHMENT CARBON BALANCE (WITHOUT AND WITH RESERVOIRS)

Or "BRINGING SEDIMENT TO LIFE"

Vientiane, October 21/22 2008

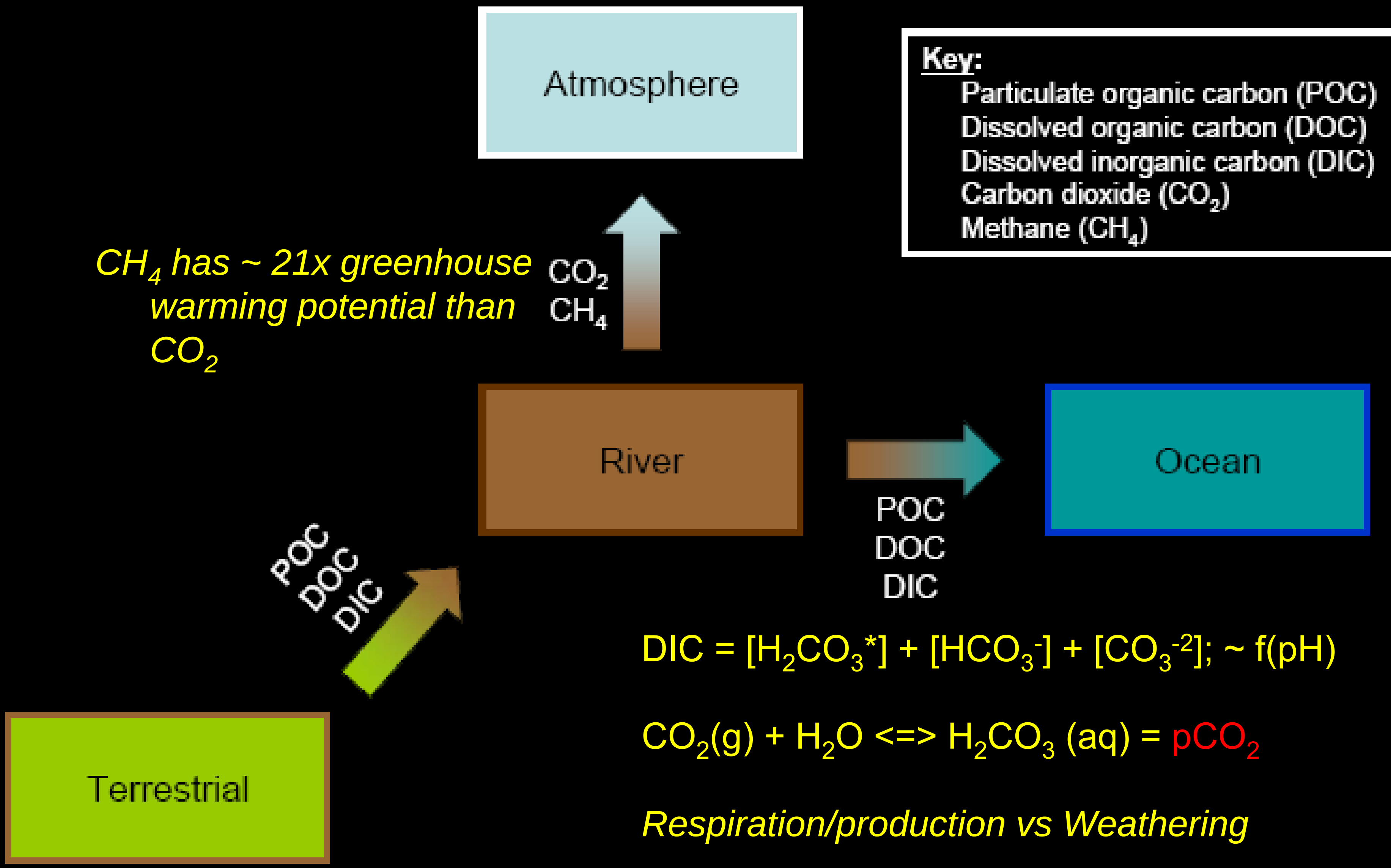
*** Jeffrey E. Richey**
School of Oceanography
University of Washington



What are the spatial (mountains to sea) and seasonal variations in the composition and magnitude of the sources and fates **of organic carbon and carbon gases in the Mekong?**

What role does the evasion (outgassing) of CO_2 and CH_4 from the river system to the atmosphere play in the carbon cycle of the humid tropics relative to fluvial carbon export to the ocean?”

Major Constituents of River Carbon Cycles



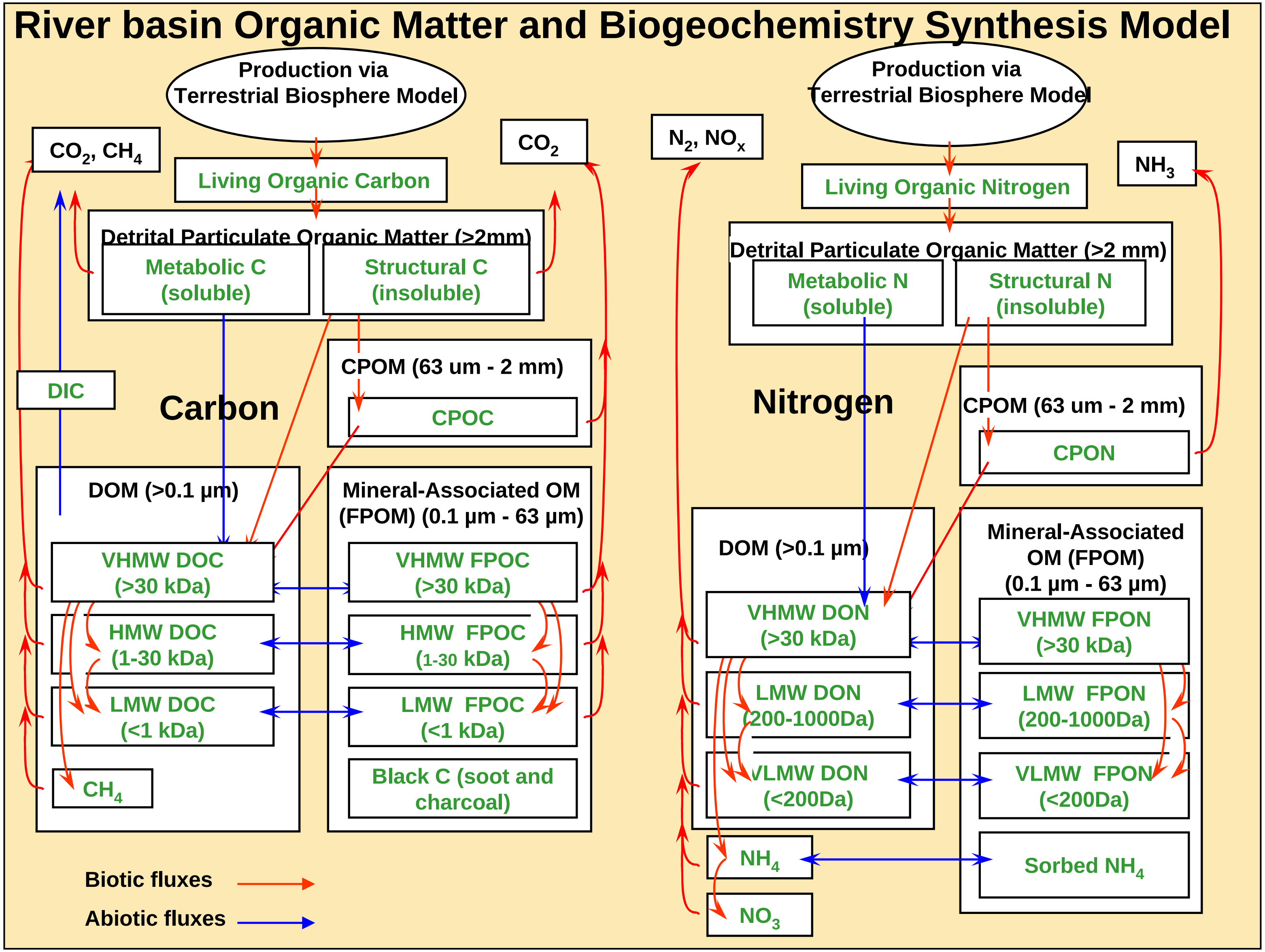
CH_4 has ~ 21x greenhouse warming potential than CO_2

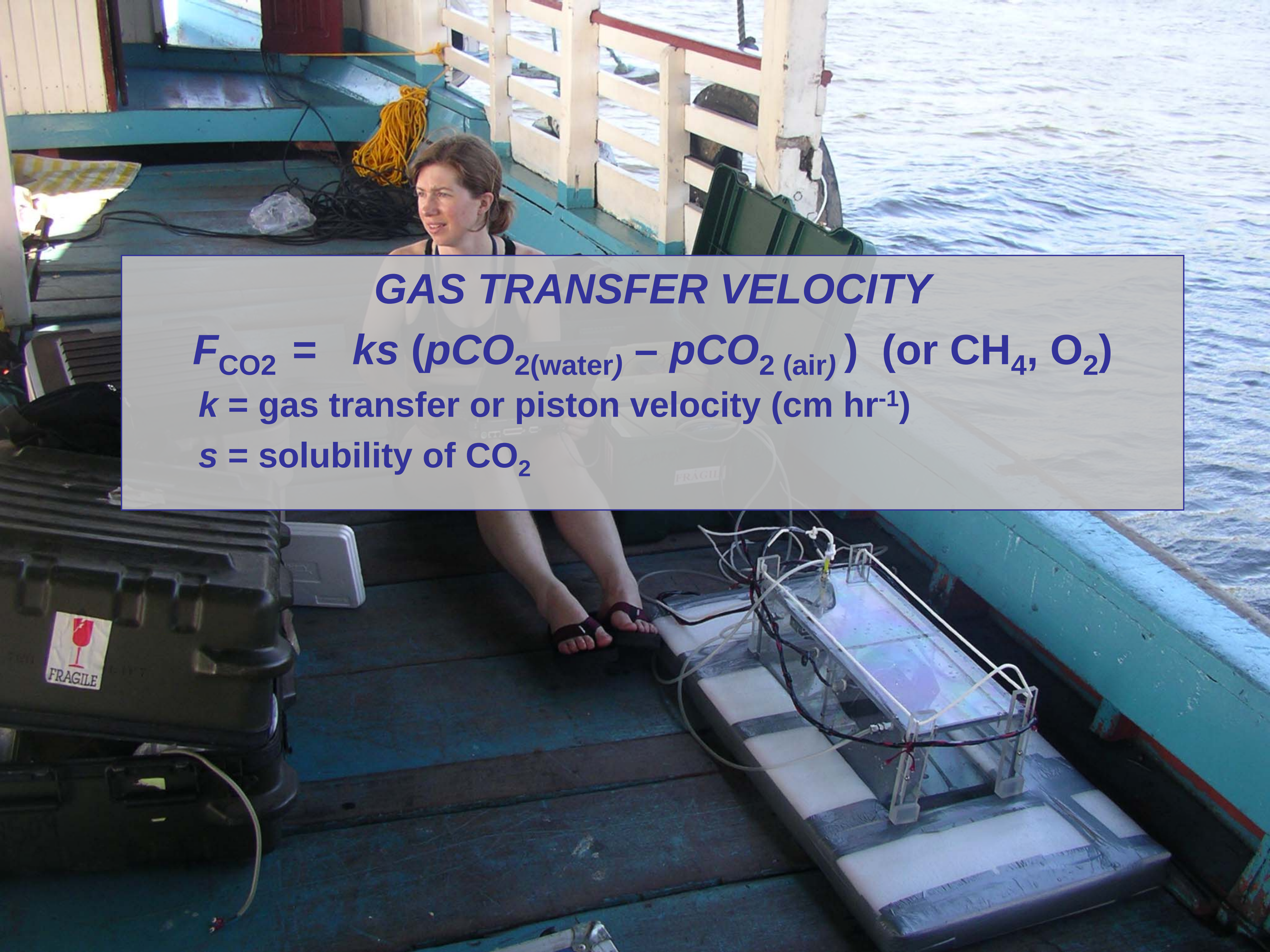
$DIC = [H_2CO_3^*] + [HCO_3^-] + [CO_3^{-2}]$; ~ f(pH)

$CO_2(g) + H_2O \Leftrightarrow H_2CO_3\ (aq) = pCO_2$

Respiration/production vs Weathering

Composition, not just “bulk,” is important and indicative





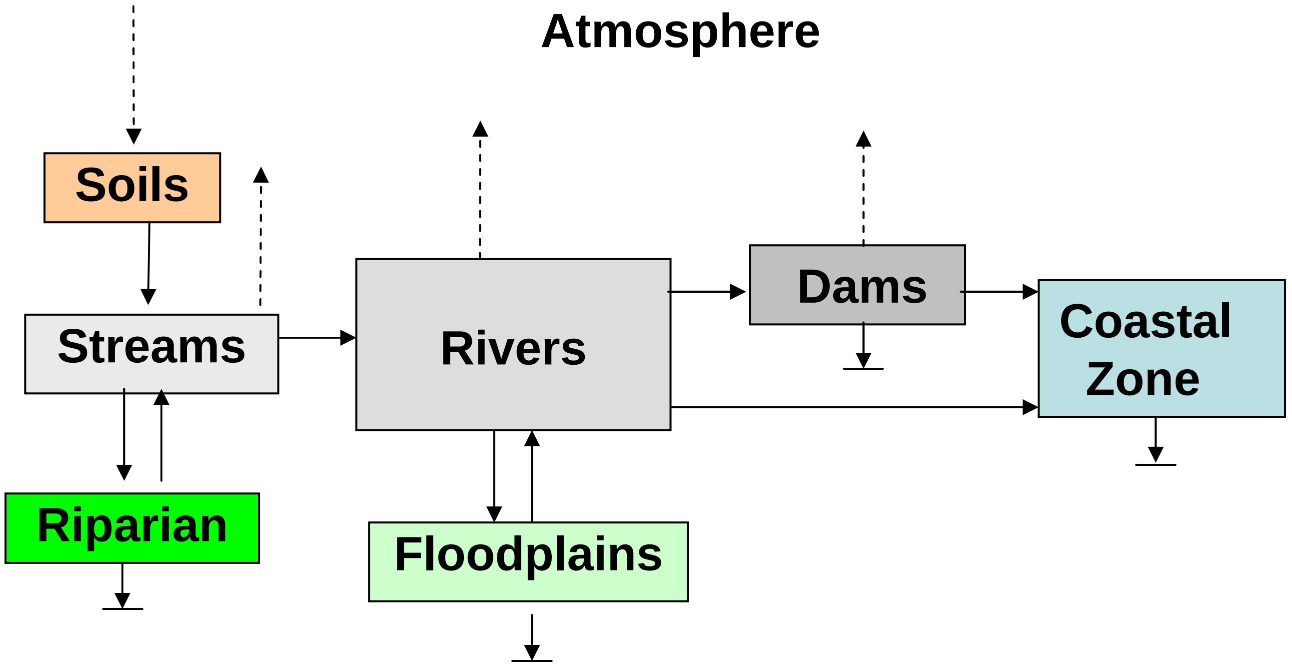
GAS TRANSFER VELOCITY

$$F_{CO2} = ks\,(pCO_{2(water)} - pCO_{2\,(air)})\ \ \text{(or } CH_4, O_2\text{)}$$

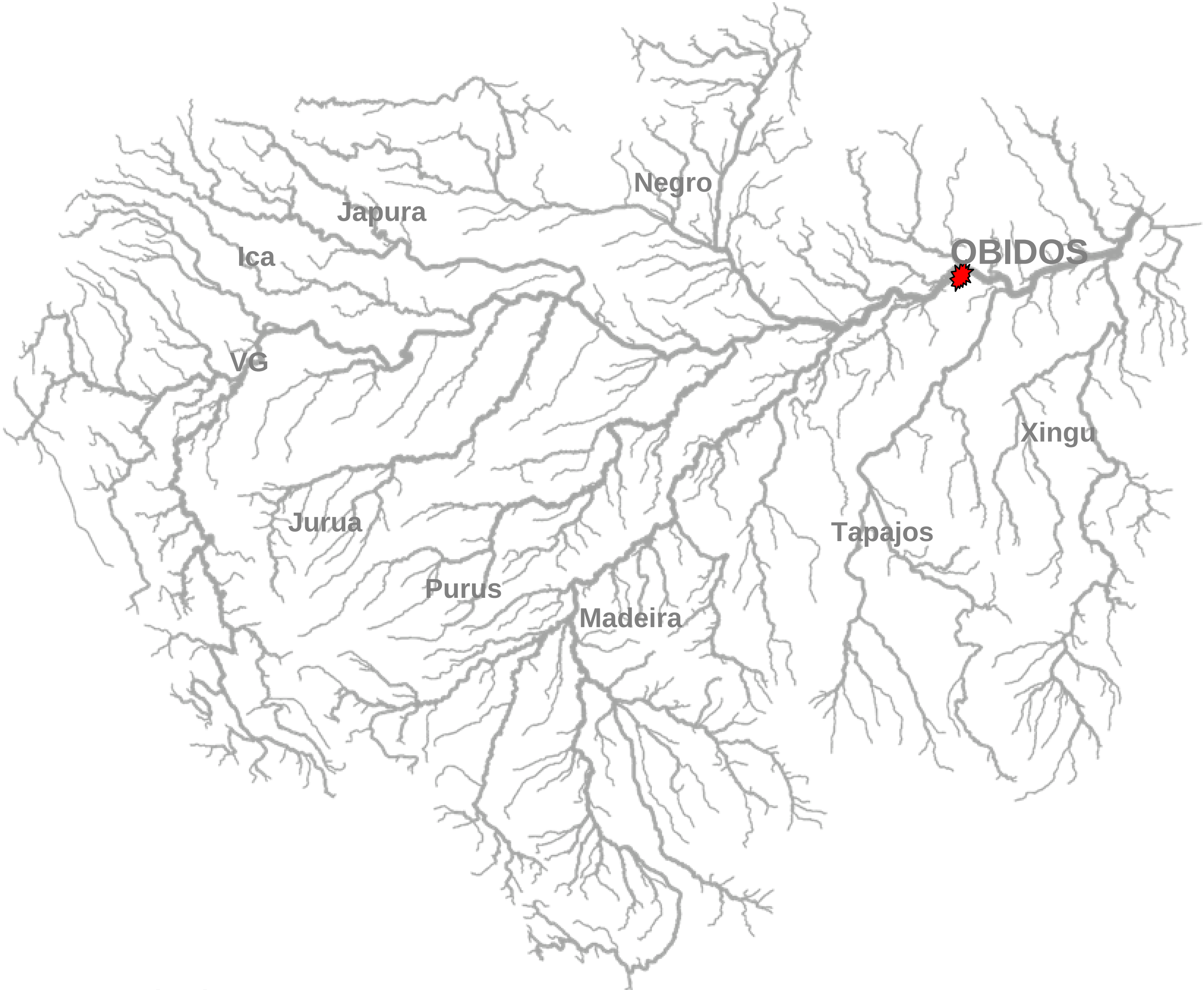
k = gas transfer or piston velocity ($cm\ hr^{-1}$)

s = solubility of CO_2

CARBON "BUDGET" OF A RIVER BASIN

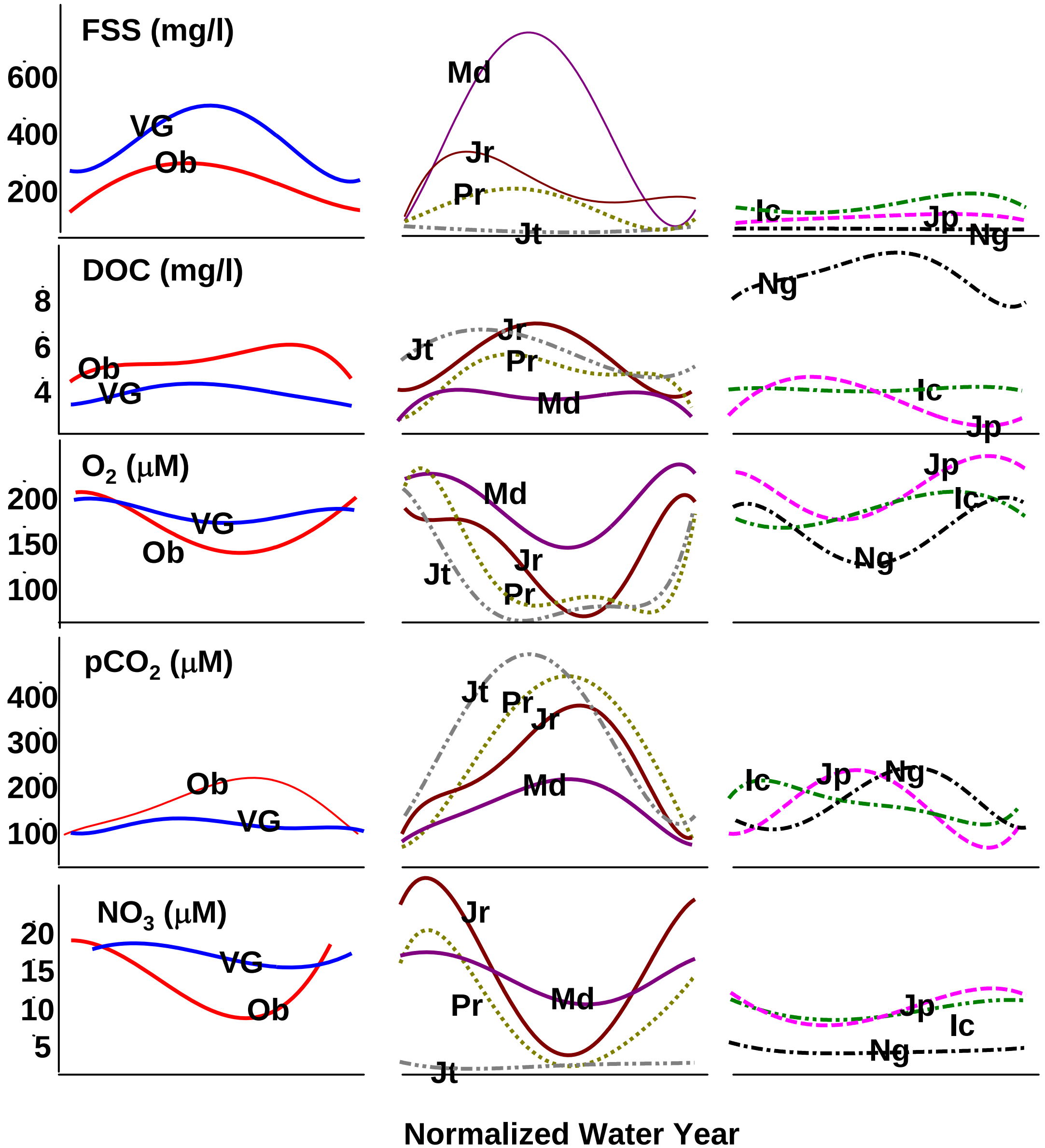


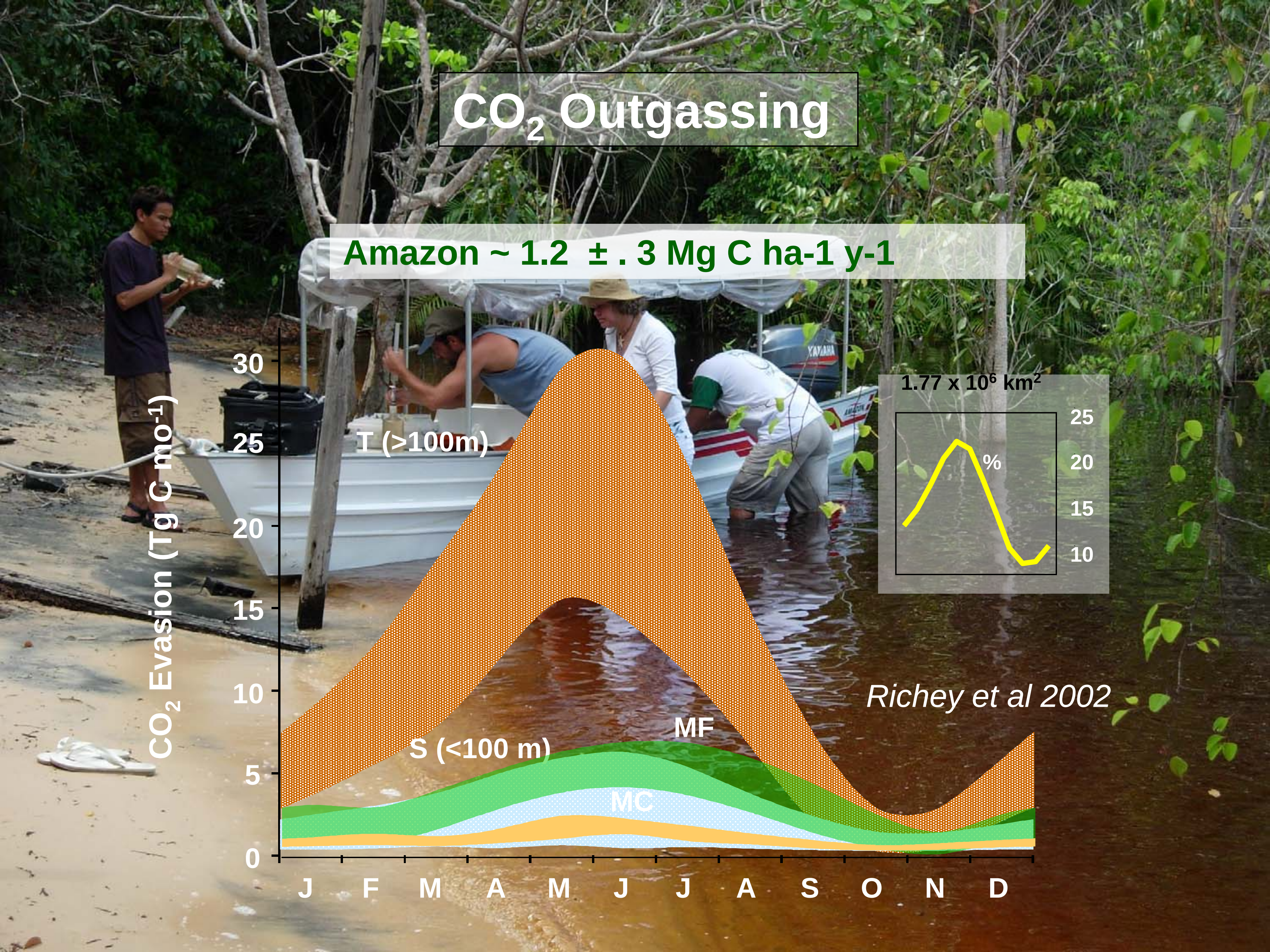
Richey, J.E. (2005). Ch. 15. Field et al (eds) A SCOPE/GCP Rapid Assessment Project. Island Press.



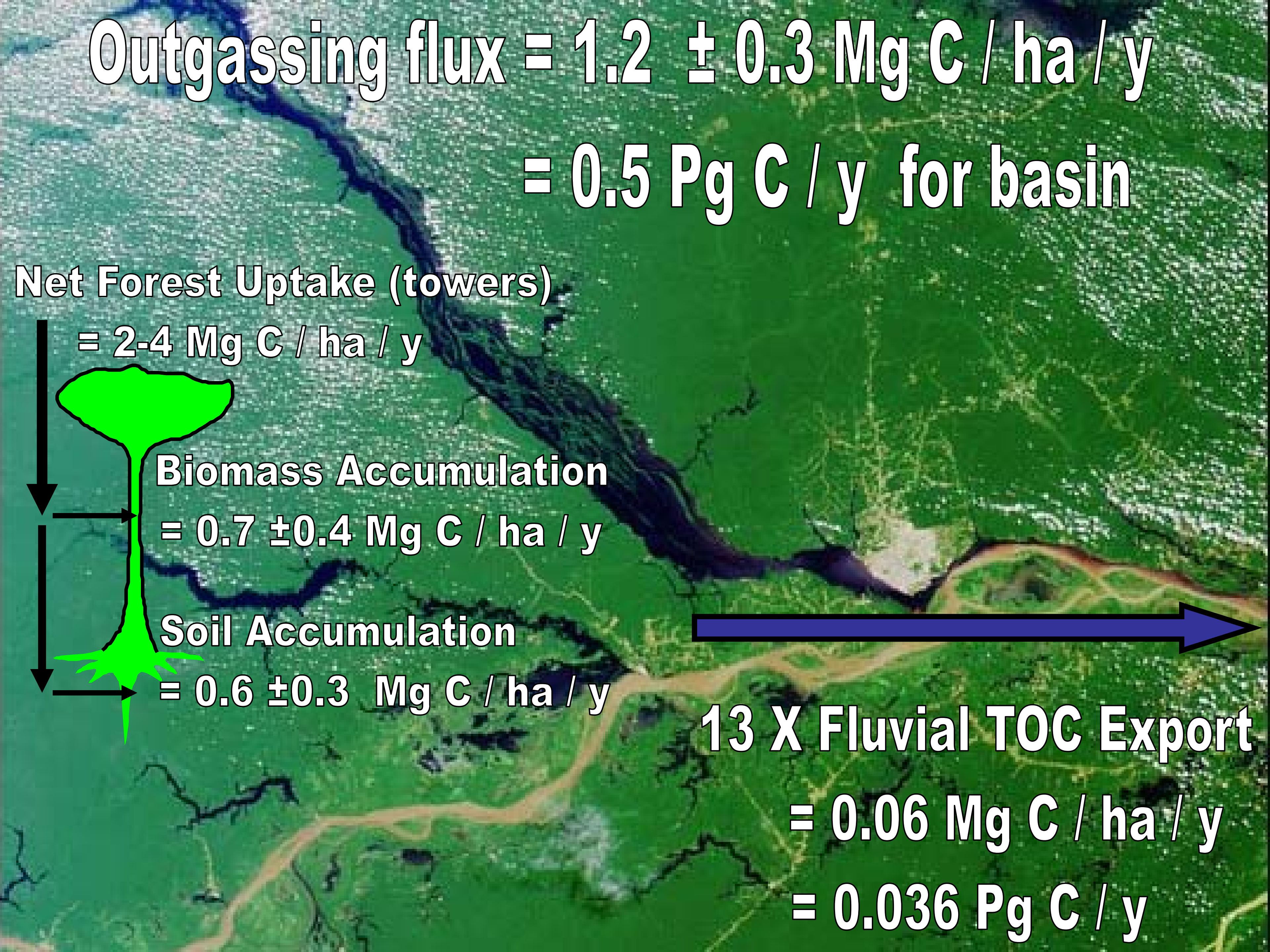
Richey BAHC Synthesis

“Chemical Hydrographs” by Basin

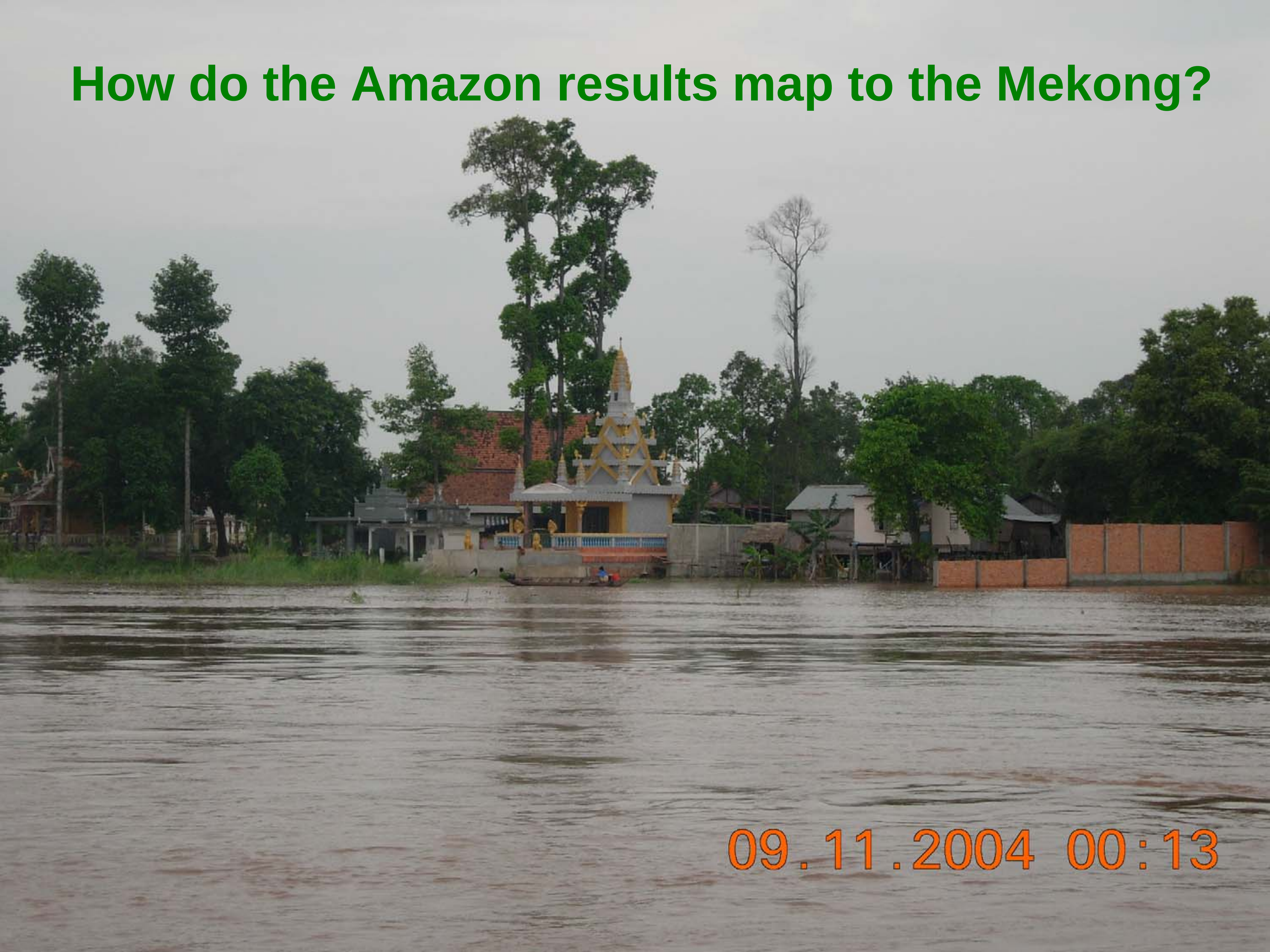




CO2 Outgassing
Amazon ~ 1.2 ± . 3 Mg C ha-1 y-1
CO2 Evasion (Tg C mo-1)
30
25
20
15
10
5
0
T (>100m)
S (<100 m)
MF
MC
J F M A M J J A S O N D
1.77 x 10^6 km^2
%
25
20
15
10
Richey et al 2002

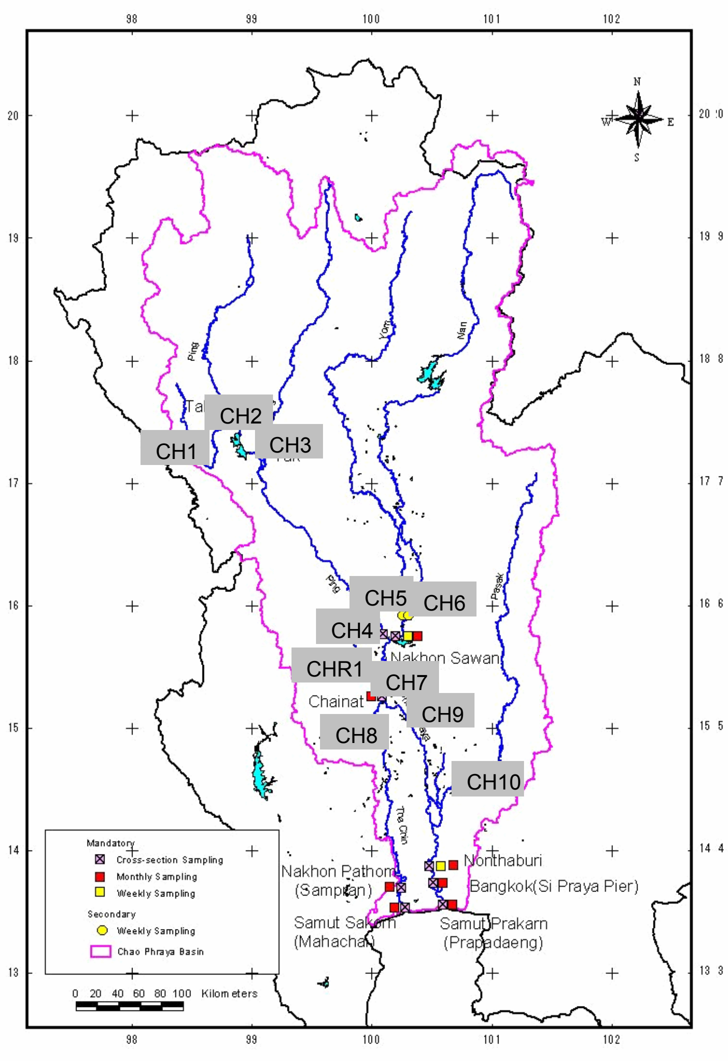

Outgassing flux = 1.2 ± 0.3 Mg C / ha / y
= 0.5 Pg C / y for basin
Net Forest Uptake (towers)
= 2-4 Mg C / ha / y
Biomass Accumulation
= 0.7 ±0.4 Mg C / ha / y
Soil Accumulation
= 0.6 ±0.3 Mg C / ha / y
13 X Fluvial TOC Export
= 0.06 Mg C / ha / y
= 0.036 Pg C / y

How do the Amazon results map to the Mekong?

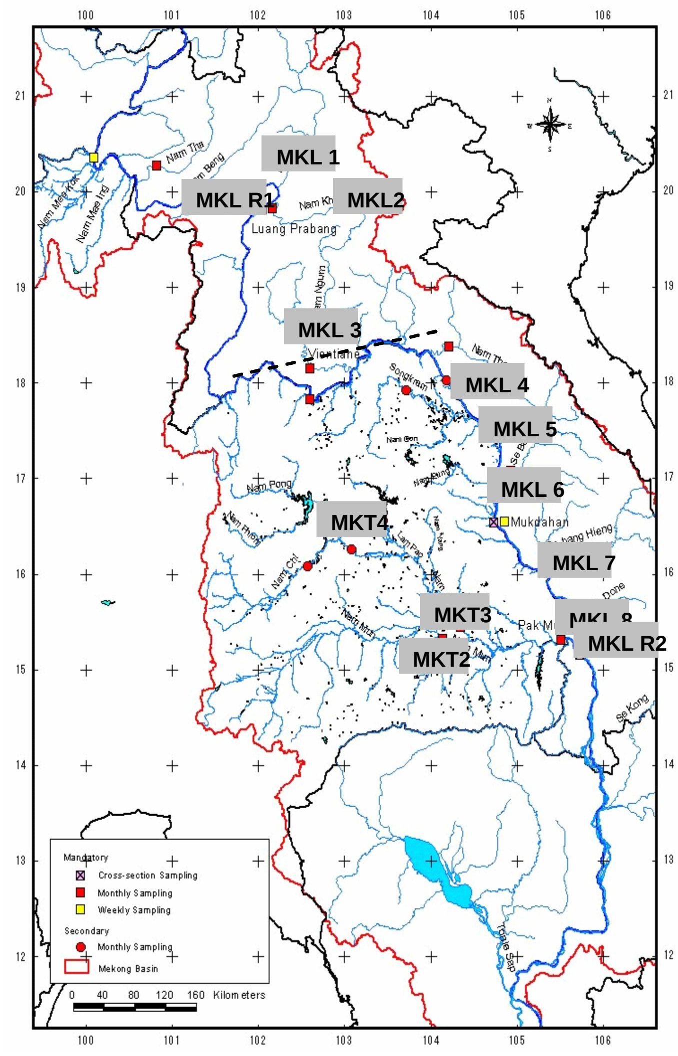


SEA-BASINS PROJECT

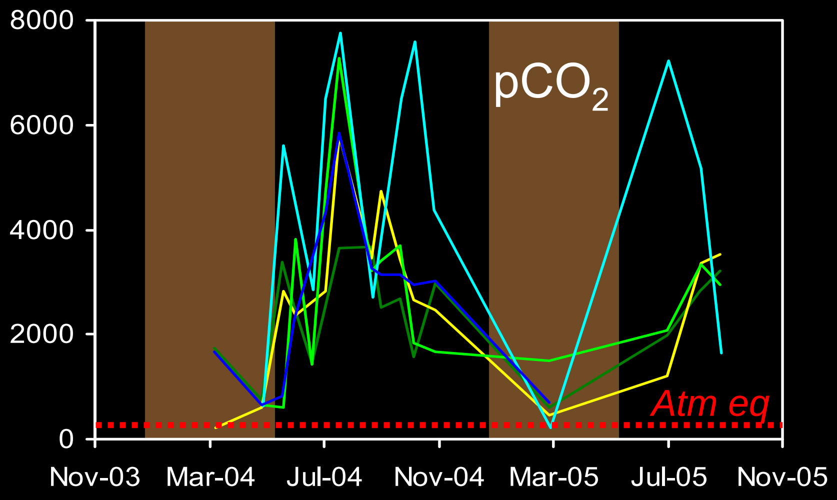
CHAO PHRYA

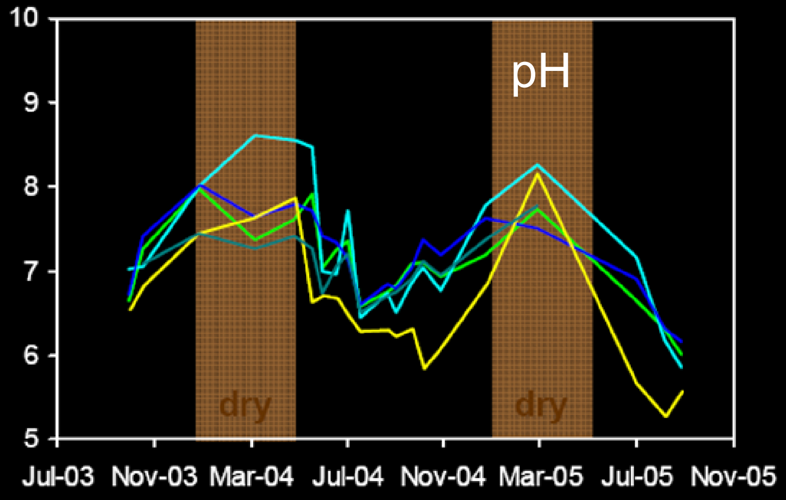


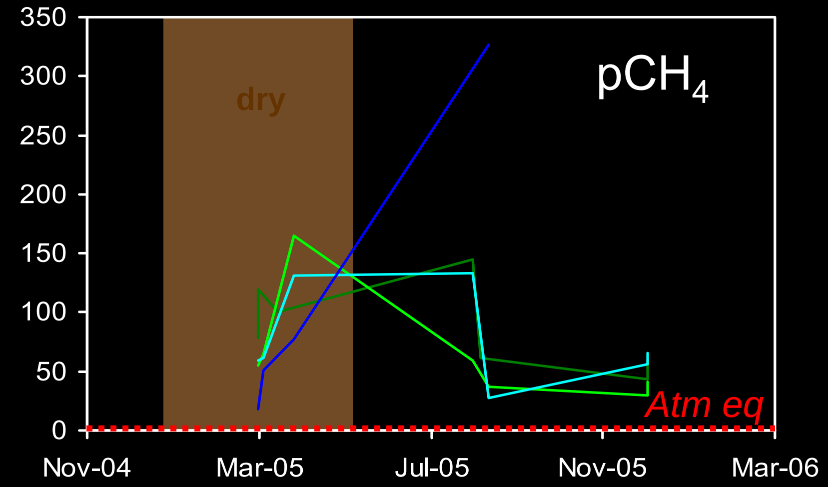
MEKONG



Seasonal Changes in Mekong Dissolved Gases

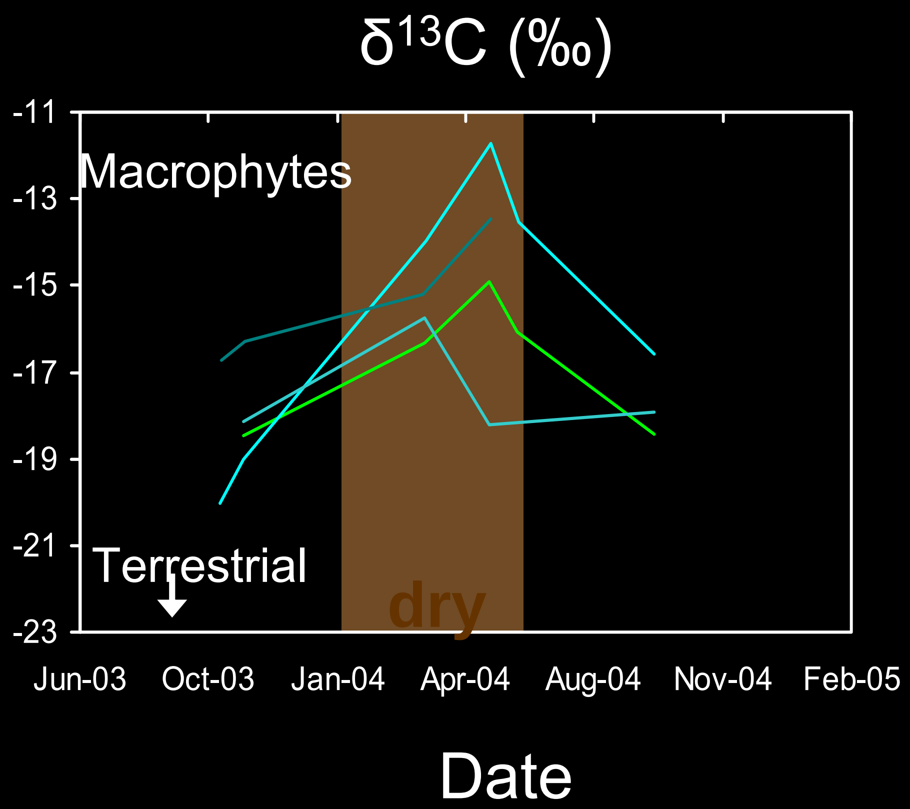


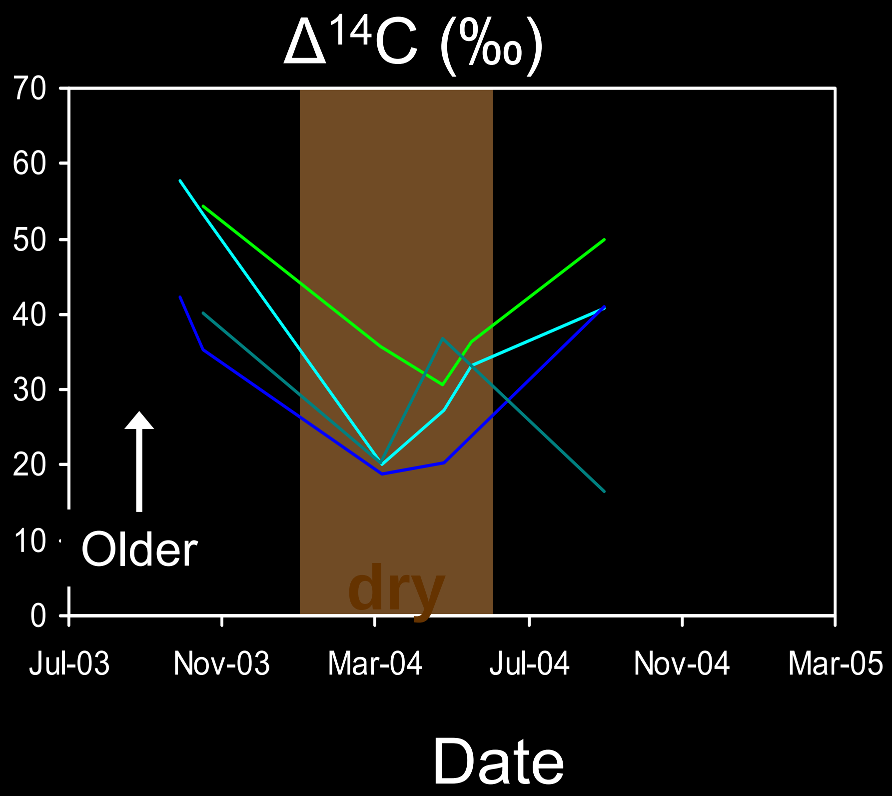




Date

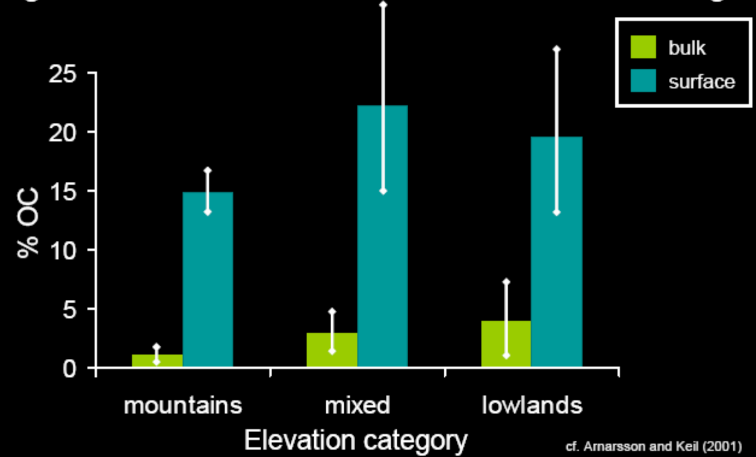
Isotope Signatures of Mekong pCO_2





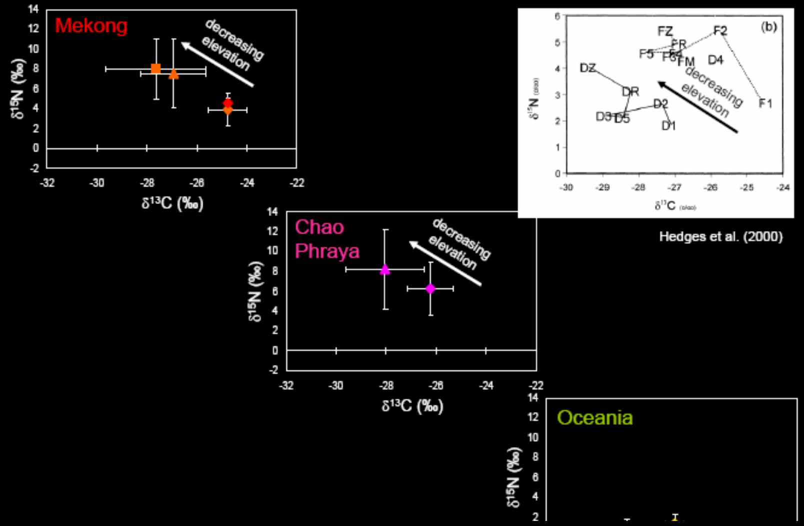
"Tracers" (organic geochemical fingerprints) of Altitude and Seasonal Composition of Mekong POC (= SS+C)

Organic carbon content and elevation in the Mekong



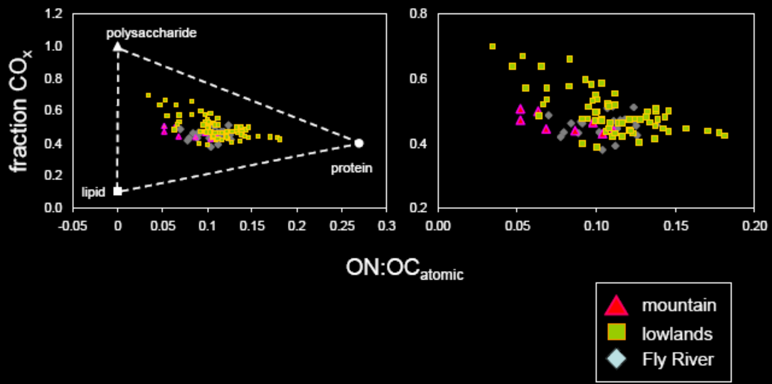
cf. Arnarsson and Keil (2001)

Enrichment factor on particle surface:

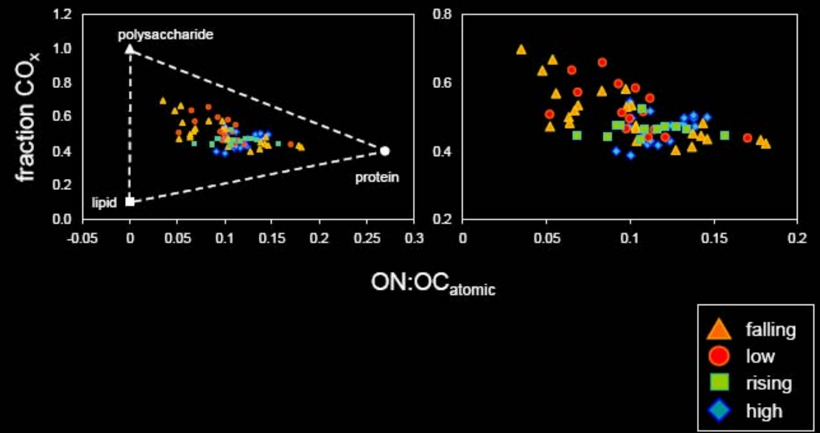


Hedges et al. (2000)

Elevational gradient in Mekong River organic matter composition



Seasonal variation in Mekong River organic matter composition



Quick Summary of Mekong C Dynamics

Carbon Cycle Details

* pCO_2 appears to be younger during the dry season and more enriched in ^{13}C. Isotopes are consistent with respiration of young organic matter or biological drawdown of ^{12}C during the dry season

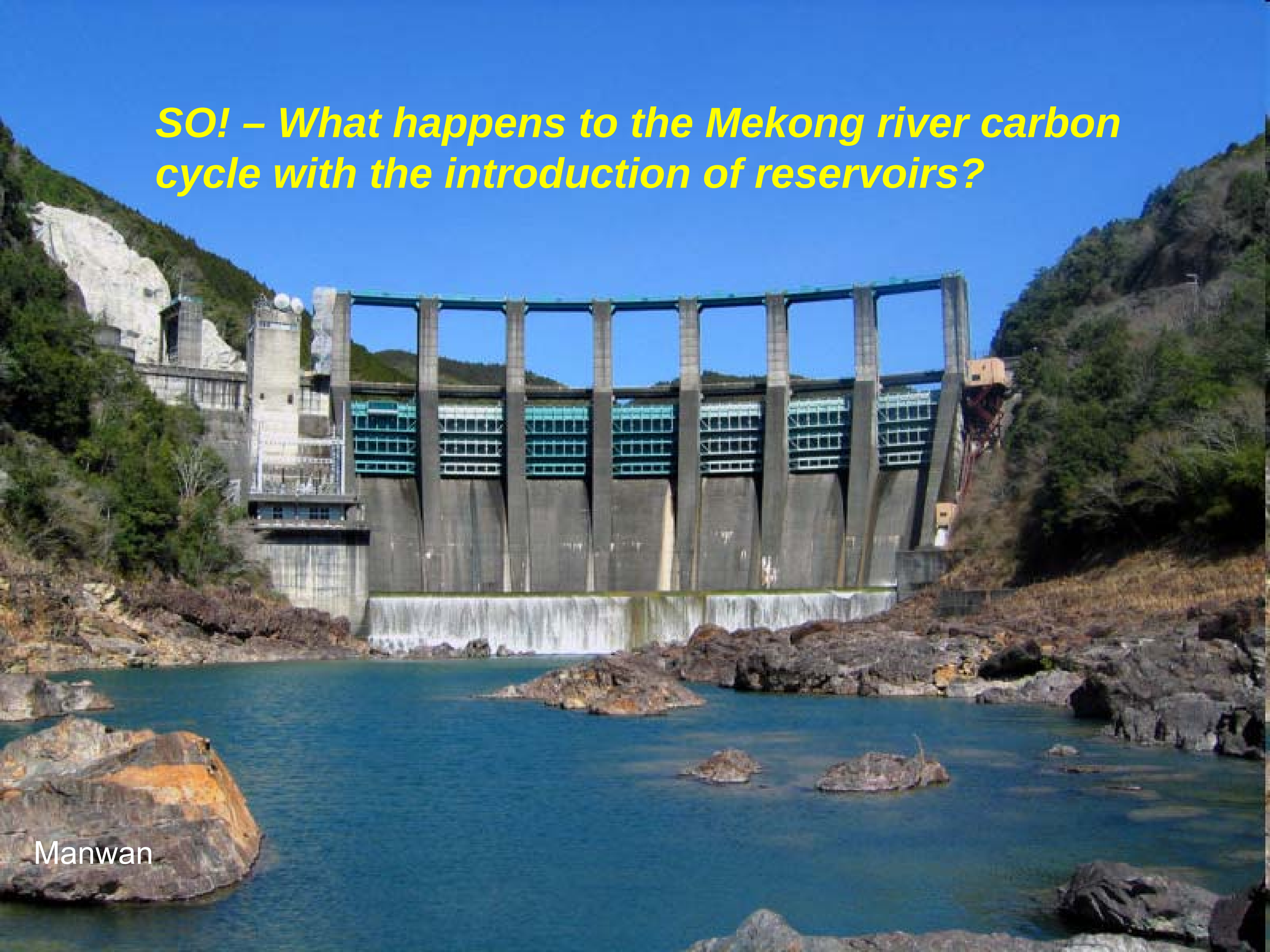
* Greater importance of older terrestrial OM during the wet season than previously suggested

Bigger Picture

* Mekong comparable in behavior to Amazon, including high pCO_2 and CH_4; hence OC indicates metabolically very active

* What happens if system state changes?

SO! – What happens to the Mekong river carbon cycle with the introduction of reservoirs?



Reservoirs and Greenhouse Gases

Jamie Skinner
World Commission on Dams

www.dams.org

Findings

Conclusion 1 : a reservoir causes a net change in GHGs from pre to post-impoundment and it is this *net change* that should be assessed for its contribution to global warming.

Conclusion 2 : carbon is flowing into the reservoir from the catchment (and perhaps from the atmosphere)

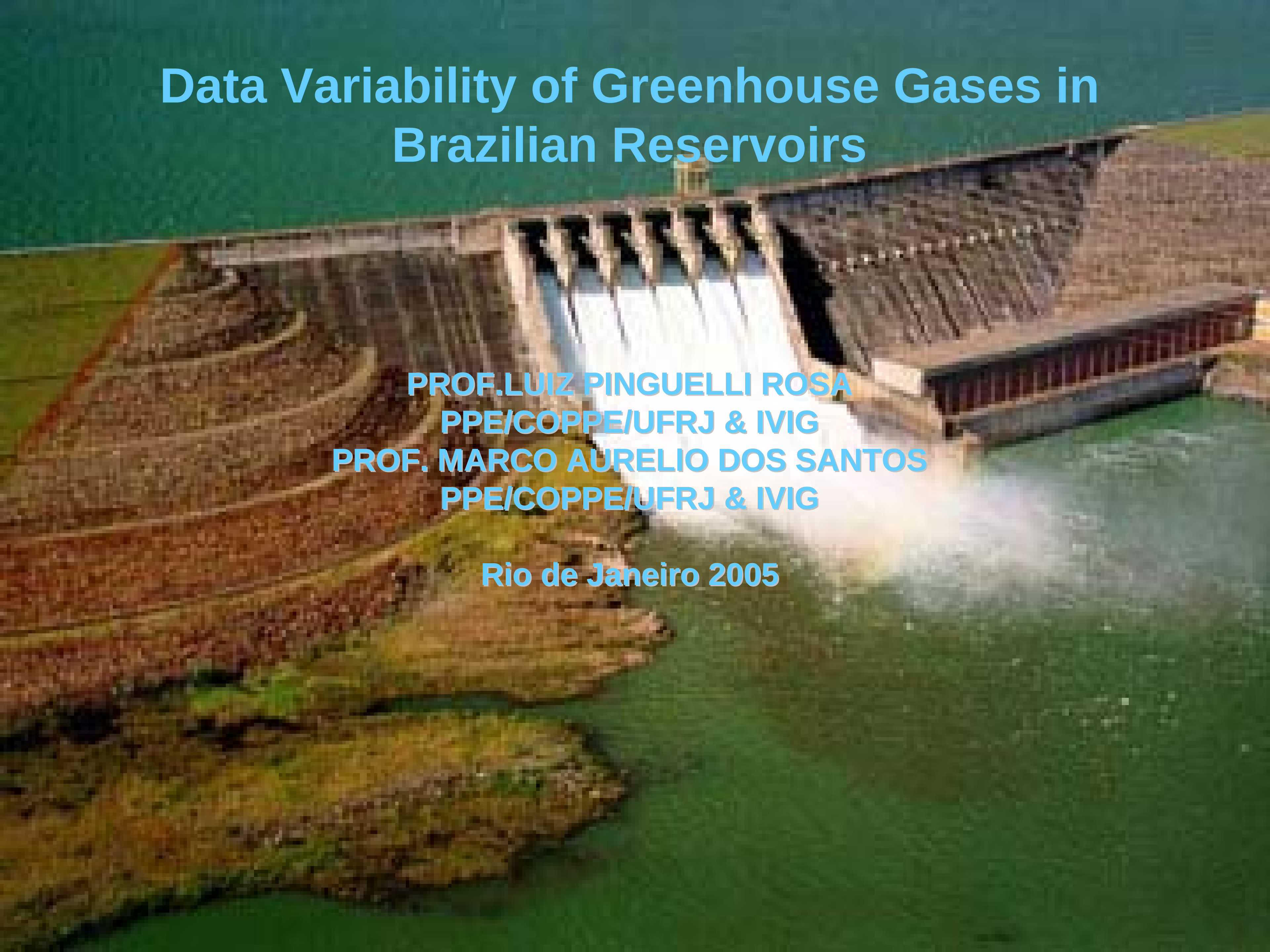
Conclusion 3 : long term studies are essential to look at full life cycle emissions over reservoir lifetimes

Few systematic studies in the humid tropics

Advice to Commission

- Hydropower cannot, *a priori*, be automatically assumed to be a 'cleaner' technology than thermal alternatives with respect to GHG emissions. Research is needed on a case by case basis to make this claim.
- In boreal climates (like Canada and Scandinavia) available studies so far suggest that emissions from hydropower reservoirs are very low.
- For Brazil, of ten dams studied, emissions vary from dam to dam with a 500-fold difference between lowest and highest. The lowest emissions are similar to Canadian lakes and reservoirs, the highest gross emissions may be in the same range as thermal energy plants.

- **The issue here is, what are the implications for the Mekong?**



Data Variability of Greenhouse Gases in Brazilian Reservoirs

PROF.LUIZ PINGUELLI ROSA
PPE/COPPE/UFRJ & IVIG
PROF. MARCO AURELIO DOS SANTOS
PPE/COPPE/UFRJ & IVIG

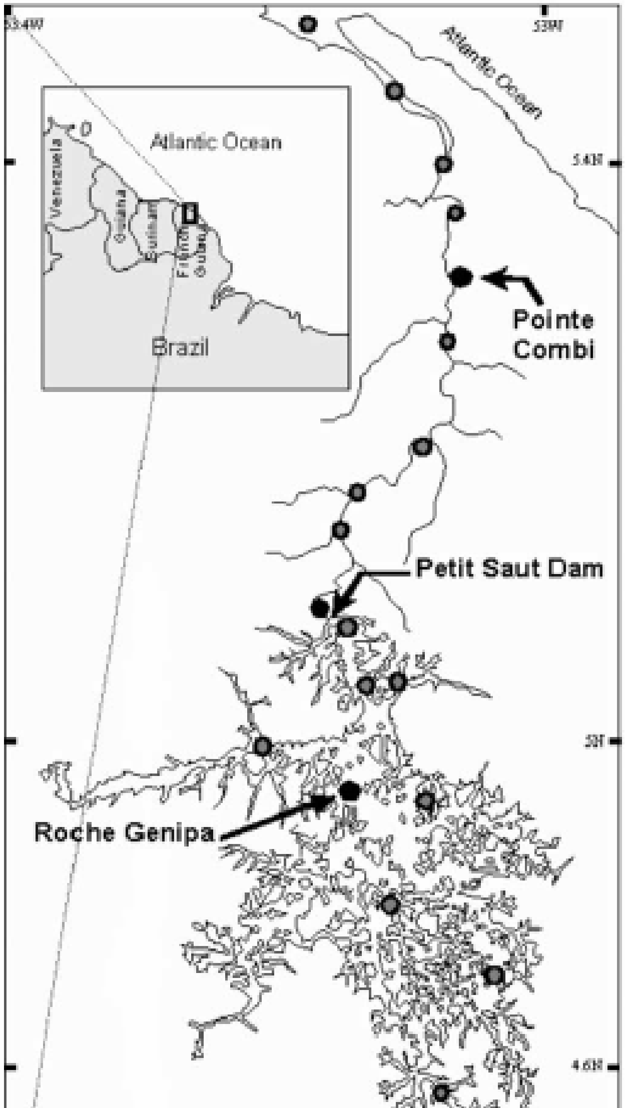
Rio de Janeiro 2005

Dam	Gas Flux by Bubbles (mg m^{-2}d^{-1})		Gas Flux by Diffusion (mg m^{-2}d^{-1})		Sum of Ebullitive and Diffusive Fluxes (mg m^{-2}d^{-1})		Range Values (mg m^{-2}d^{-1})			
	CH_4	**CO_2**	**CH_4**	**CO_2**	**CO_2**	**CH_4**	**CO_2 Bubbles**	**CO_2 Diffusion**	**CH_4 Bubbles**	**CH_4 Diffusion**
Miranda	18.5	0.2	27.4	3,796	3,796	45.9	0.01 – 0.87	223 – 41,358	0.03 – 72.6	2.19 – 168.2
Tres Marias	55.9	4.01	8.4	2,373	2,369	64.3	0.01 – 23.3	168 – 7,346	0.04 – 402.5	0.66 – 70.75
Barra Bonita	3.1	0.05	19.5	1,537	1,537	22.6	0.002 – 0.19	83 – 20,391	0.0004 – 15.48	5.1 – 59.3
Segredo	1.9	0.03	5.7	601	601	7.6	0.02 – 0.25	165 – 16,218	0.01 – 15.4	2.14 – 14.59
Xingó	19.6	0.09	30.6	2,440	2,440	50.2	0.0004 – 1.9	341 – 17,239	0.78 – 407.3	3.54 – 92.9
Samuel	13.6	0.4	10.8	6,808	6,807	24.4	0.01 – 1.2	2,200 – 24,283	0.07 – 37.6	6.13 – 17.16
Tucuruí	2.5	0.07	10.9	6,516	6,516	13.4	0.03 – 0.5	457 – 32,291	0.92 – 21.2	4.44 – 28.53
Itaipu	0.6	<<1	7.9	-864	-864	8.5	0.001 – 0.009	- 4,061 – (-120)	0 – 1.9	0.9 – 57.30
Serra da Mesa	66.3	1.5	39.2	3,973	3,972	105	0.06 – 37.4	(-6,048) – 10,178	0.15 – 2,546.9	(-24.3) - 355

- ***A great variability was found in the intensity of emissions in Brazilian reservoirs***

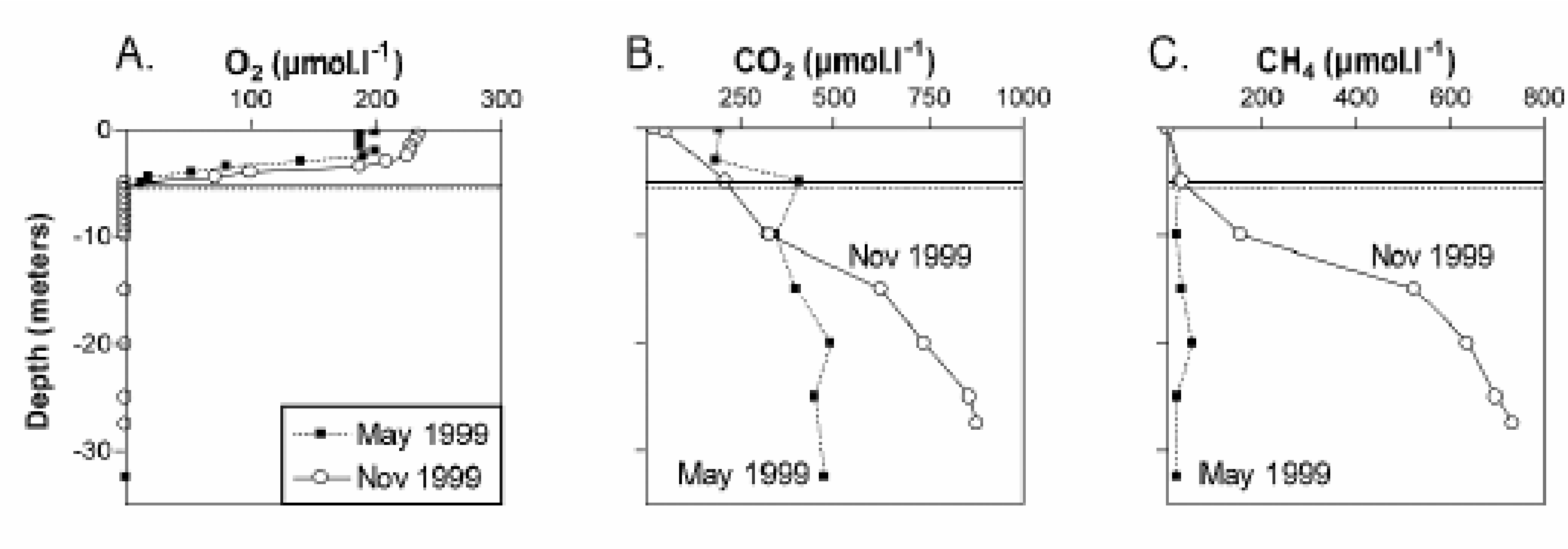
- **Relatively low correlation between emissions and the age of the dam,**

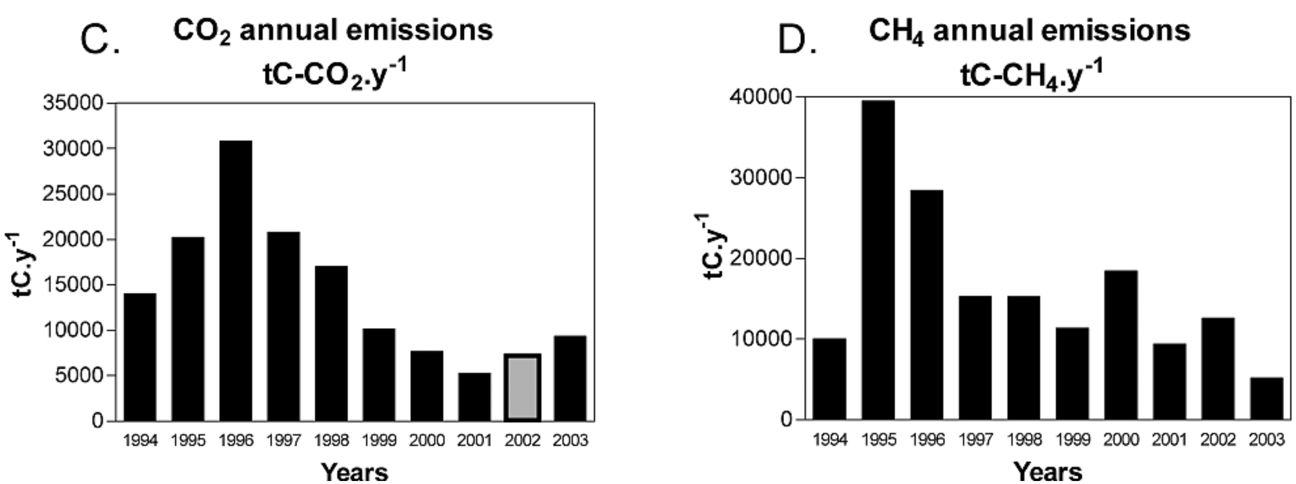
- **Probably the emissions result not only from the decomposition of pre-existing terrestrial biomass, but also organic matter swept down the upstream drainage basin … in addition to organic matter produced in the dam itself (i.e. phytoplankton).**



Carbon dioxide and methane emissions and the carbon budget of a 10-year old tropical reservoir (Petit Saut, French Guiana).

Abril et al. 2005. Global Biogeochemical Cycles 19


A.
O2 (µmol.l-1)
100
200
300
0
-10
-20
-30
Depth (meters)
May 1999
Nov 1999
B.
CO2 (µmol.l-1)
250
500
750
1000
Nov 1999
May 1999
C.
CH4 (µmol.l-1)
200
400
600
800
Nov 1999
May 1999

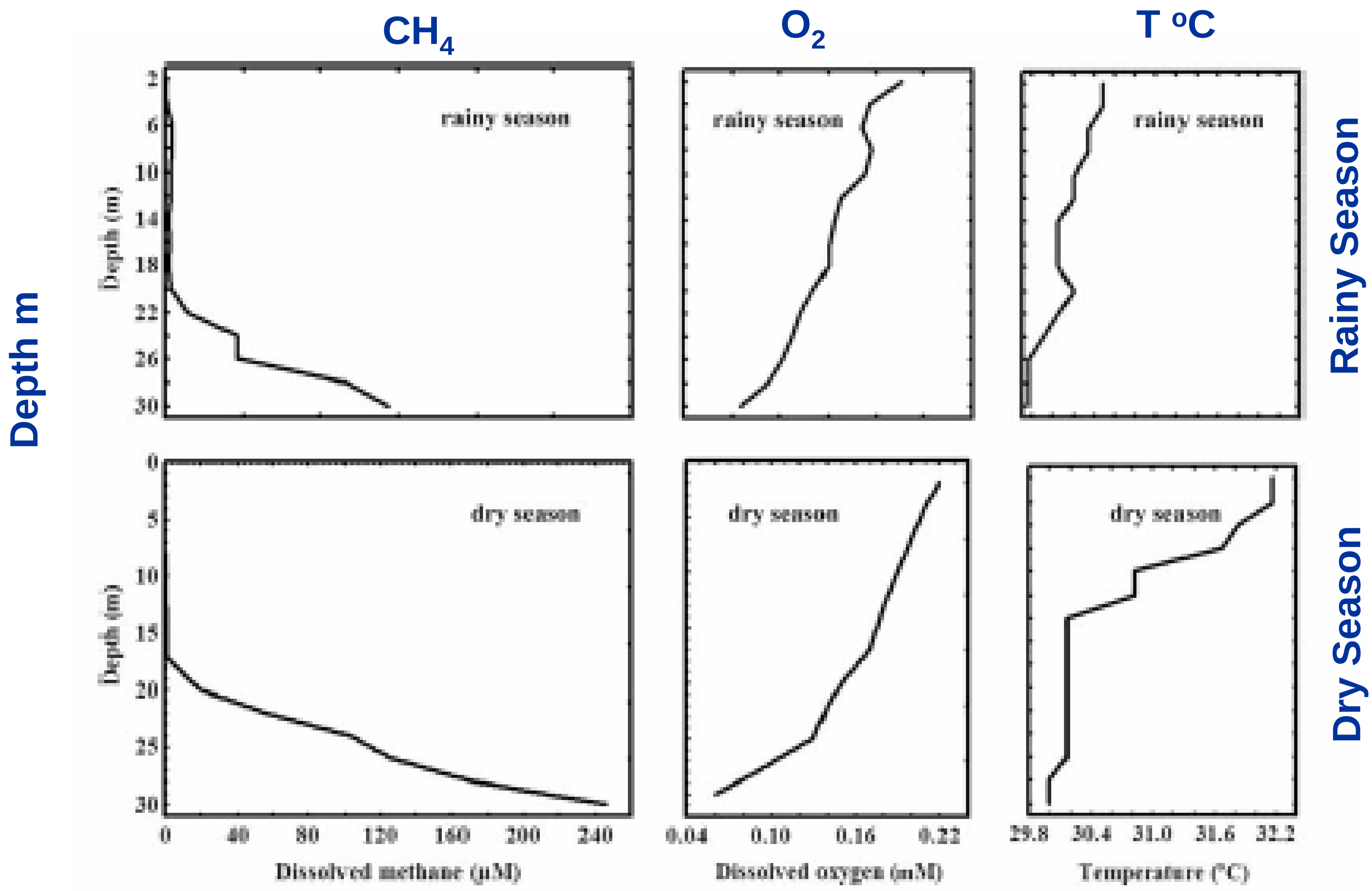

C.
CO2 annual emissions
tC-CO2.y-1
35000
30000
25000
20000
15000
10000
5000
0
tC.y-1
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Years
D.
CH4 annual emissions
tC-CH4.y-1
40000
30000
20000
10000
0
tC.y-1
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
Years

- **Degassing at an aerating weir downstream of the turbines has become the major pathway for CH_4 emissions, reaching 70% of the total CH_4 flux.**

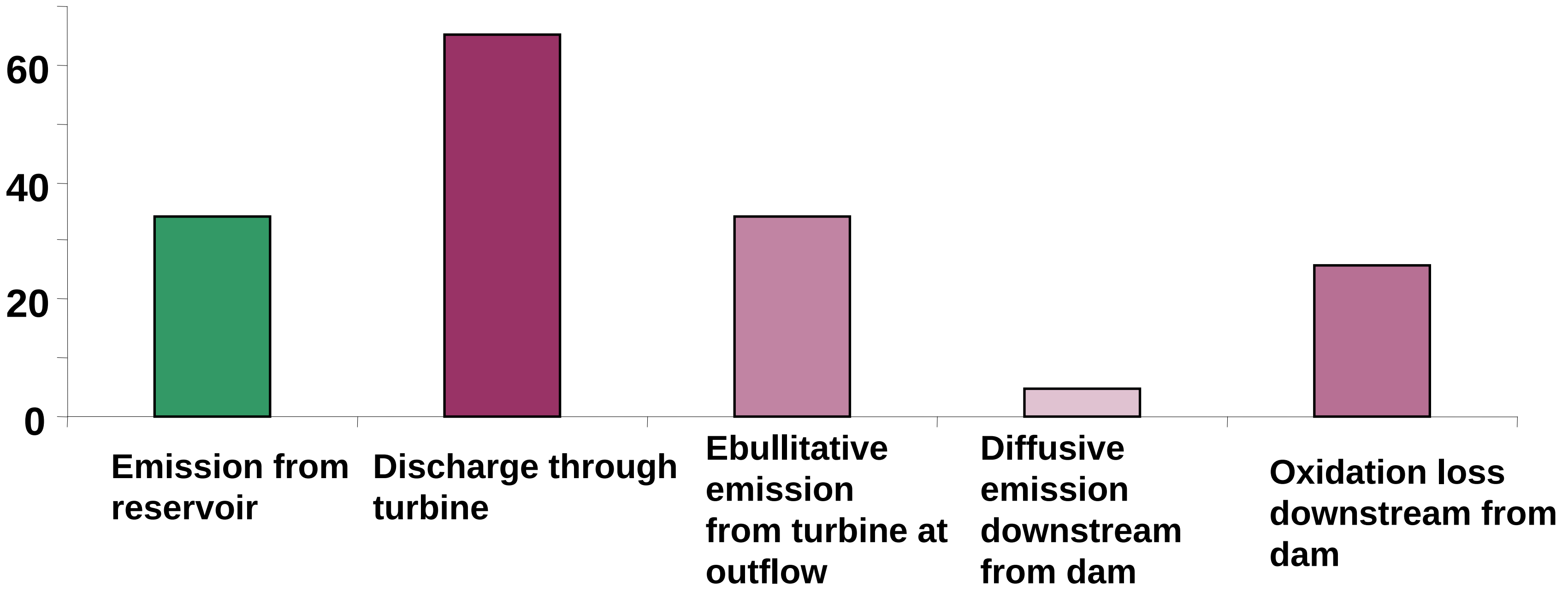
- **…. 10 years after impounding, the flooded terrestrial carbon is still the predominant contributor to the gaseous emissions.**

- **Results confirm the significance of GHG emissions from tropical reservoir but stress the importance of:**
- **considering all the gas pathways upstream and downstream of the dams and**
- **taking into account the reservoir age when upscaling emissions rates at the global scale.**

Methane release below a tropical hydroelectric dam (Balbina). Kemenes et al. 2007. GRL 34



CH_4 Emissions downstream of Balbina reservoir



CH4 Emissions downstream of Balbina reservoir

When downstream methane release is accurately assessed, the contribution of all hydroelectric reservoirs to regional emissions and global atmospheric warming is expected to increase significantly.

Assuming a warming potential for methane 21 times greater than that of carbon dioxide [Lelieveld et al., 1998], the total emission from the Balbina hydroelectric system alone has the atmospheric warming potential of 8% of all fossil fuels consumed in Sao Paulo

IMPLICATIONS FOR A CASCADE OF RESERVOIRS ON THE MEKONG:

Mekong organic carbon/gas dynamics are very "active," fed by terrestrial inputs as well as in situ production. The implication is that a cascade of reservoirs could be expected to have a very significant GHG footprint