Towards a Large-Scale Aquatic Carbon Model for the Amazon Basin

Erica A. Howard[1], Michael T. Coe[1], Jonathan A. Foley[1], and Marcos Heil Costa[2]

[1]Center for Sustainability and the Global Environment (SAGE) - Gaylord Nelson Institute for Environmental Studies, University of Wisconsin-Madison, USA. [2] Departamento de Engenharia Agricola, Universidade Federal de Viçosa, Brazil.

Center for Sustainability and the Global Environment (SAGE)
Gaylord Nelson Institute for Environmental Studies
University of Wisconsin-Madison
1710 University Avenue
Madison, WI 53726 USA
http://www.sage.wisc.edu
eahoward@wisc.edu 1.608.265.8720 tel
mtcoe@wisc.edu 1.608.265.4038 tel
jfoley@wisc.edu 1.608.265.9119 tel

Departamento de Engenharia Agricola,
Universidade Federal de Viçosa, Viçosa, MG, Brazil
mhcosta@ufv.br

1. Abstract

The work of Richey et al. (2002) has focused attention on the importance of carbon dioxide efflux to the atmosphere from waters of the Amazon basin. We are taking steps toward quantifying this flux on the scale of the whole basin. Our approach uses a combination of an ecosystem land surface model (IBIS – Foley et al. 1996, Kucharik et al. 2000), a hydrological routing model (HYDRA – Coe 2000, Coe et al. 2002), and a new aquatic carbon processing module that we are incorporating into HYDRA.

Here, we describe the current state of this C model and our future plans for development. We drive the model with IBIS-derived estimates of surface and groundwater from the terra firme, várzea, and igapó, and with empirically-derived estimates of C inputs. To allow for seasonal fluctuations in the aquatic-terrestrial transition zone, for each timestep HYDRA simulates the volume of water contained in each of four chemically-distinct zones in each grid cell: pelagic (open water), littoral (near-shore), floodable lowland, and terra firme (upland). With this information the model simulates the dynamics among six different pools of aquatic C: autotrophs, coarse particulate organic carbon (CPOC), fine particulate organic carbon (FPOC), dissolved organic carbon (DOC), dissolved inorganic carbon (DIC), and sediment. Water and C are explicitly advected to downstream grid cells. The amount of CO_2 efflux from the water surface is calculated for each grid cell, in each timestep. This model is being calibrated with empirical data from the CAMREX project and LBA sources. As the model is developed, it will eventually be driven with a combination of annual climate datasets, soils and topographical data, and remote-sensing-based maps of wetland extent.

2. Driving question

How does carbon efflux from water to the atmosphere vary among different hydrochemical environments in the Amazon Basin?

3. Aquatic carbon model

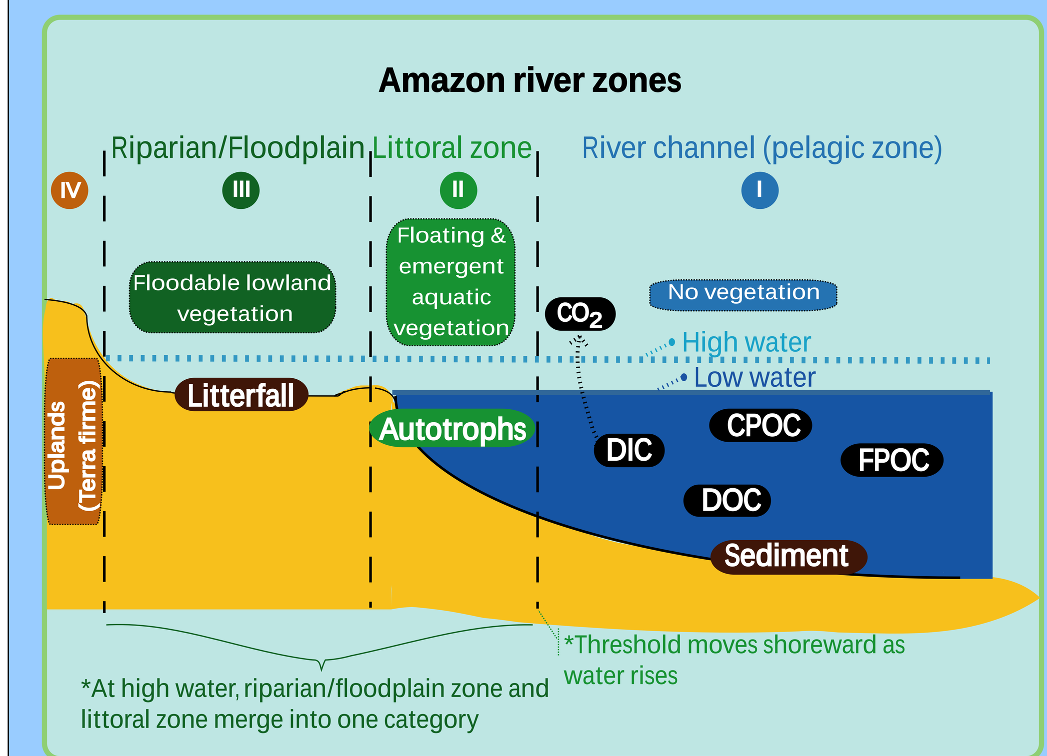


Figure 1. Schematic framework for separating lowland ecosystems into different hydro-chemical zones

Background

We are developing an aquatic carbon model within the existing HYDRA water balance model to handle the routing and chemical transformations of carbon supplied *from* terrestrial ecosystems (including floodplains and wetlands), in-stream production, and the atmosphere *to* Amazonian rivers.

Here we present our first attempts to use a simplified, aspatial prototype of the model to simulate aquatic carbon cycling in different Amazonian aquatic environments. This version, developed using Stella modelling software, allows us to investigate the behavior of the model for single, unconnected points (which would be individual grid cells at 5-minute resolution in HYDRA).

River zones

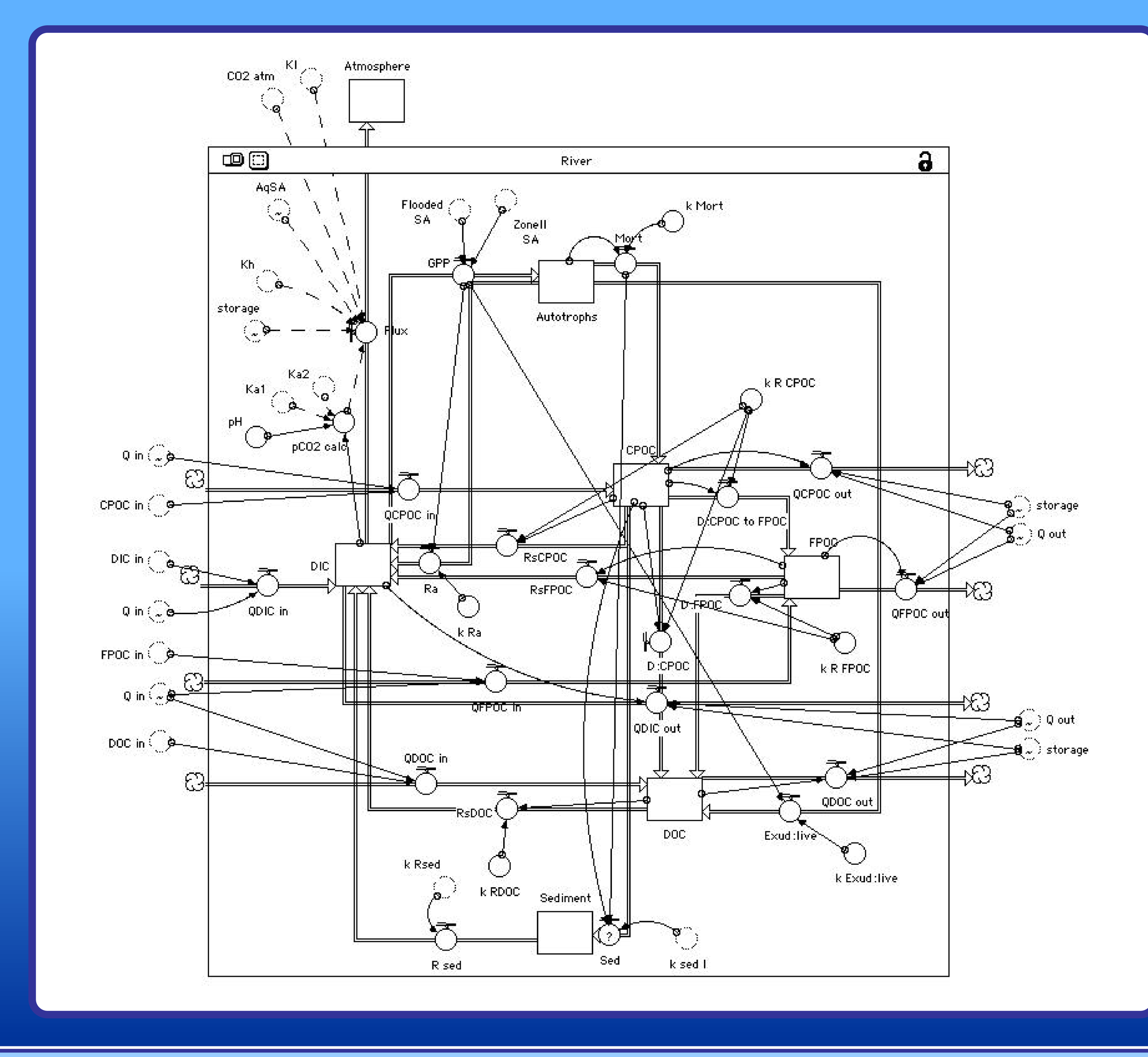
The model simulates carbon cycling for a section of river or floodplain. It handles the flow and transformation of carbon among 3 different zones (Figure 1) :

(I) the open river (pelagic zone);
(II) the near-shore environment (littoral zone);
(III) the riparian/floodplain zone.

Model description

- Carbon is stored in 7 different pools in each grid cell:
  - autotrophs;
  - fine particulate organic carbon (FPOC);
  - coarse particulate organic carbon (CPOC);
  - dissolved organic carbon (DOC);
  - dissolved inorganic carbon (DIC);
  - sediments;
  - the atmosphere.
- Water (with a prescribed C load) enters the grid cell as discharge, and leaves the cell as outflow.
- Volume and surface area of the littoral zone and the floodplain are tracked at each timestep.
- Submerged aquatic plants and plankton take up DIC through autotrophy (GPP) at a constant rate depending on area (littoral zone + floodplain).
- Autotrophs die, respire, or leach DOC exudate.
- CPOC decomposes to FPOC and DOC, is respired, or becomes sediment.
- FPOC decomposes to DOC and is respired.
- DOC and sediments are respired.
- Super-saturated DIC is emitted to the atmosphere as CO_2.

Figure 2.
Schematic of the aquatic carbon model in Stella



4. Simulations

Using an *aspatial* prototype of the aquatic carbon model, we ran 6 simulations to represent major hydrochemical environments of the Amazon Basin:

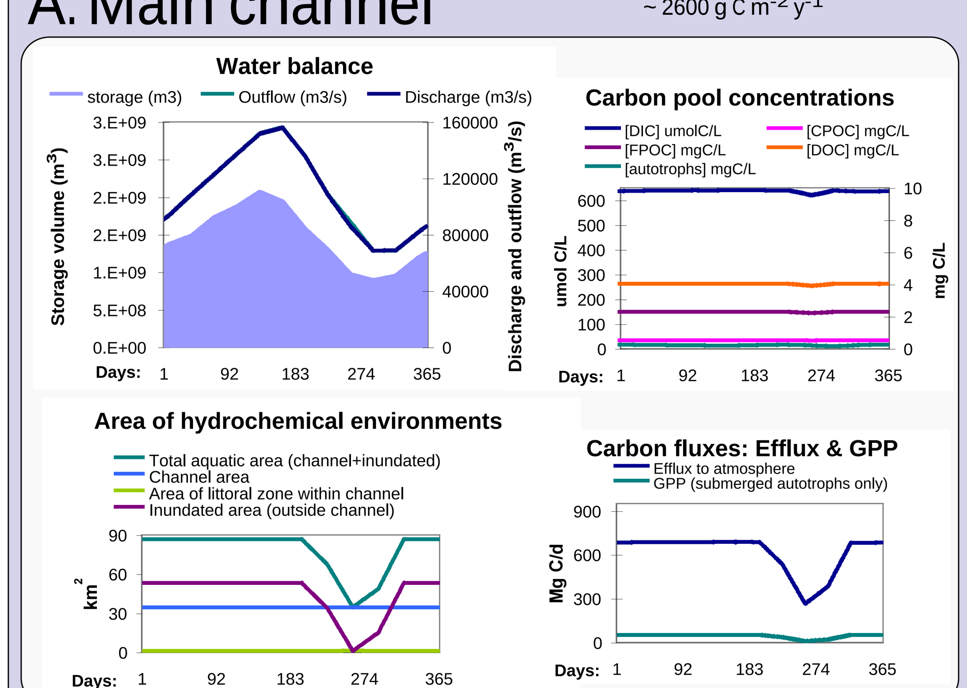
- effective area of each simulation: land area ~ 80-90 km²;
- major characteristics of simulations - see table below;
- hydrology and geomorphological attributes derived from IBIS/HYDRA and from empirical relationships;
- drove simulations with modeled river discharge, storage, and flooding for 1983;
- assumed a 10 m littoral zone on each side of river channel when not in flood;
- biogeochemical inputs and parameters - derived from several published studies (see references) of field measurements from Amazonia (e.g., Rio Purus, R. Amazonas, R. Negro, Lago Calado, etc.);
- ran each simulation for 3 years; results from year 2 (after spin-up) are presented here.

				Initial Conditions						
Simulation	**Width at flood initiation**	**Height at flood initiation**	**Maximum area inundated (including river)**	**pH**	**Temp**	**pCO2**	**[CPOC]**	**[FPOC]**	**[DOC]**	**GPP**
	m	m	km2		deg C	umol C/L	mg C/L	mg C/L	mg C/L	g C/m2/d
Mainstem, Central Amazon	3561	16.1	85.7	6.85	28.0	152	0.50	2.2	4.0	0.820
Large whitewater tributary	1246	13.0	85.6	6.49	28.0	248	0.15	1.0	4.1	0.820
Medium whitewater tributary	943	12.0	85.2	7.27	28.0	141	0.07	1.5	3.9	0.820
Small whitewater tributary	60	3.6	1.0	6.16	26.3	102	0.19	1.8	4.4	0.820
Varzea lake (whitewater floodplain)	42	2.6	85.8	6.85	28.0	152	0.50	2.2	4.0	0.820
Large blackwater tributary	1859	14.0	85.7	4.96	28.0	100	0.00	0.1	8.7	0.366

5. Preliminary results

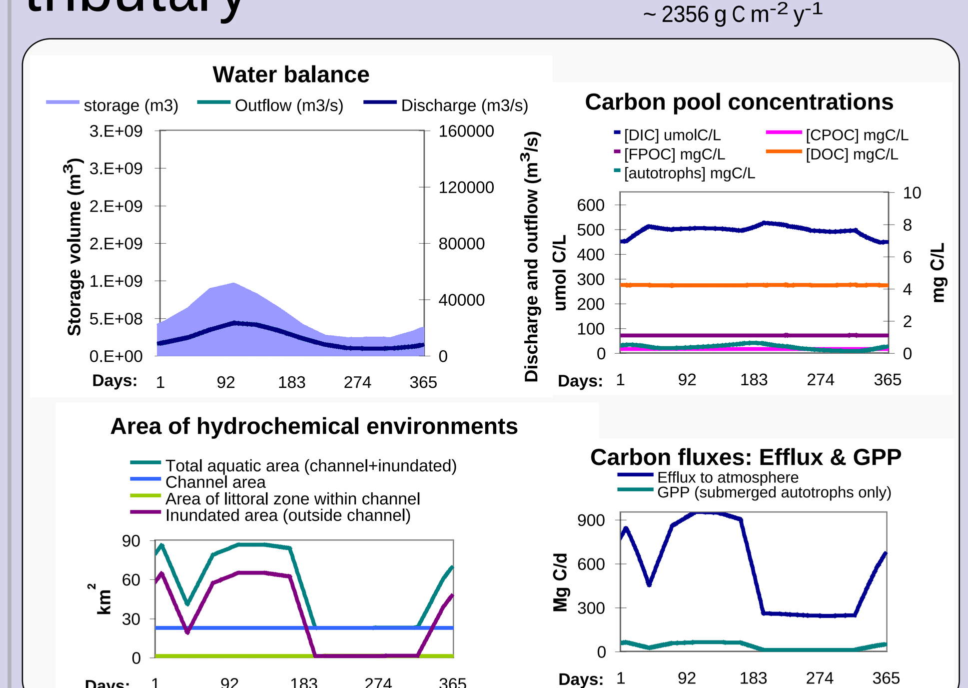
A. Main channel

Efflux per unit of aquatic surface: ~ 2600 g C m^{-2} y^{-1}



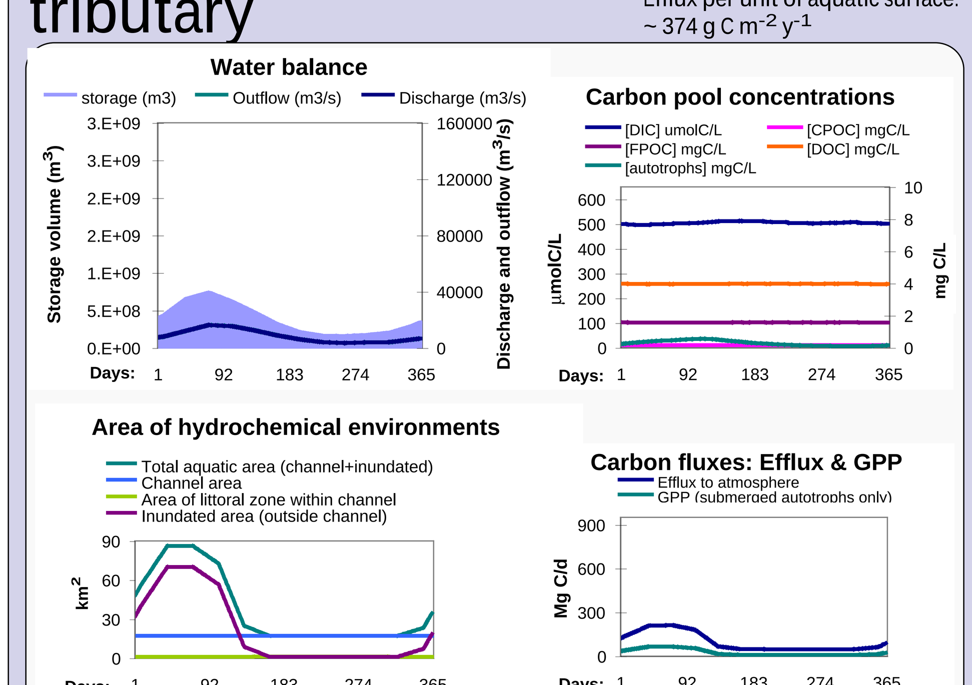
B. Large whitewater tributary

Efflux per unit of aquatic surface: ~ 2356 g C m^{-2} y^{-1}



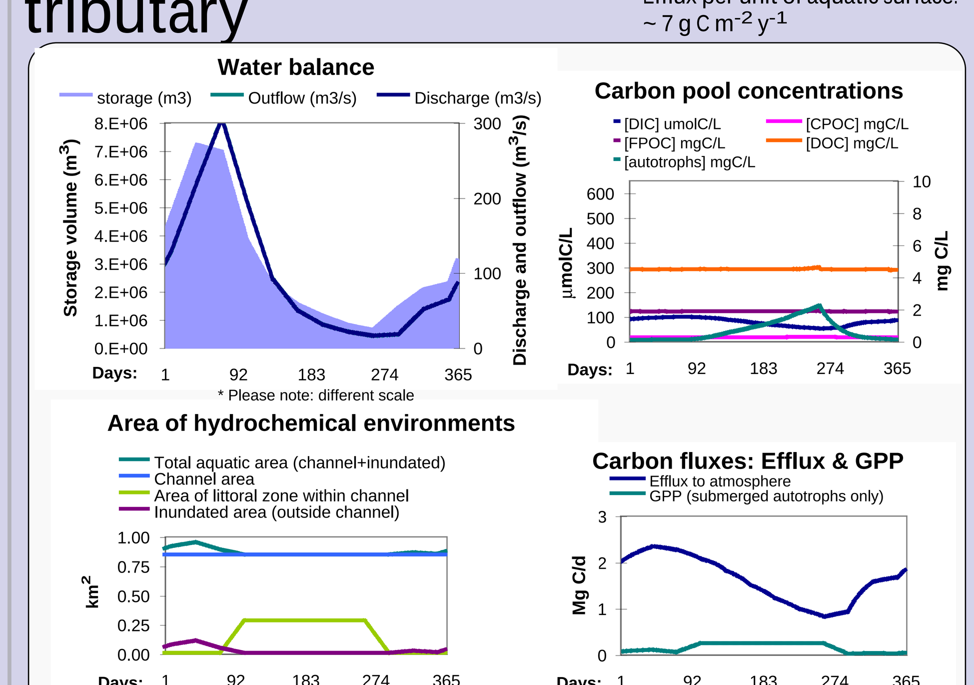
C. Medium whitewater tributary

Efflux per unit of aquatic surface: ~ 374 g C m^{-2} y^{-1}



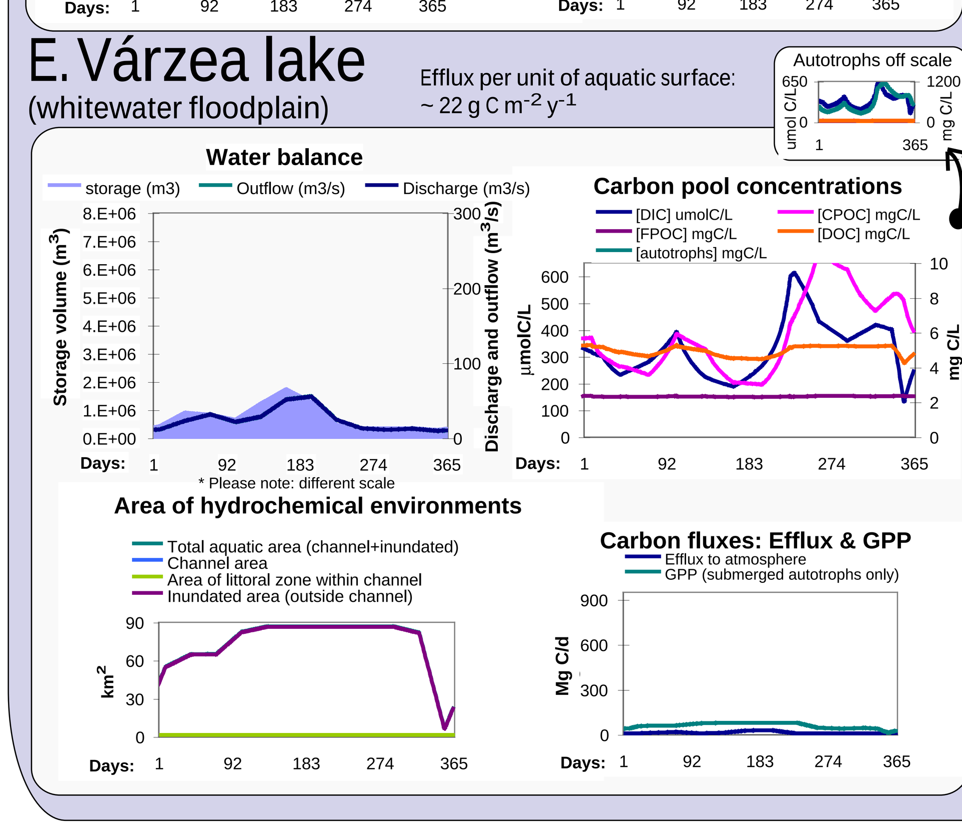
D. Small whitewater tributary

Efflux per unit of aquatic surface: ~ 7 g C m^{-2} y^{-1}



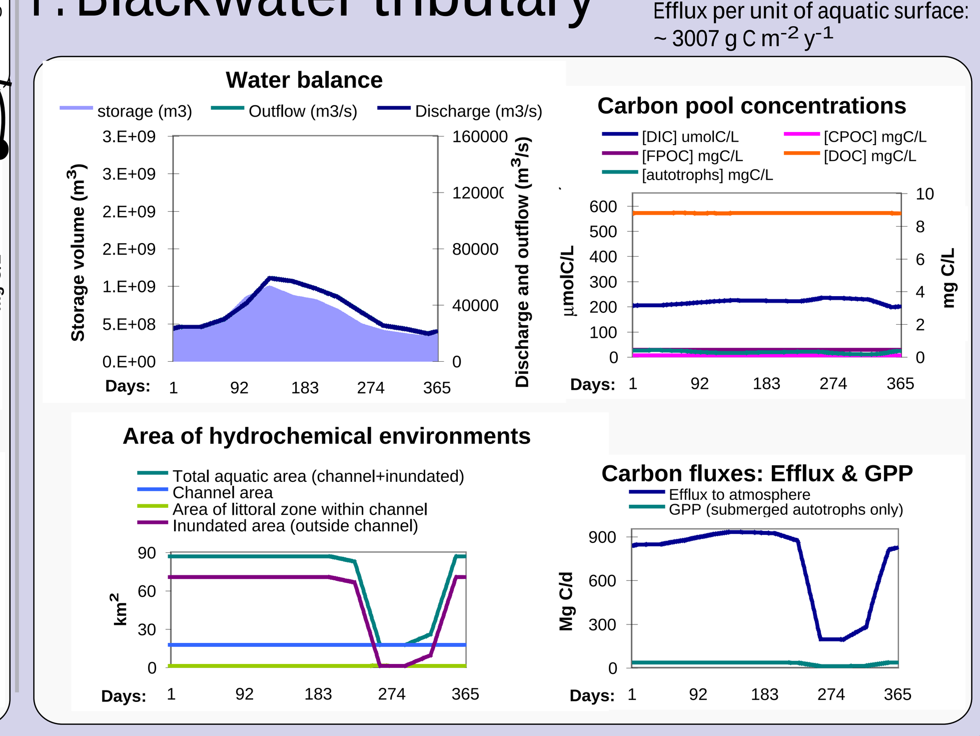
E. Várzea lake
(whitewater floodplain)

Efflux per unit of aquatic surface: ~ 22 g C m^{-2} y^{-1}



F. Blackwater tributary

Efflux per unit of aquatic surface: ~ 3007 g C m^{-2} y^{-1}



6. Discussion

This prototype model shows interesting interactions between hydrology and biogeochemistry, leading to very different efflux values of C to the atmosphere from different kinds of environments.

Richey et al. (2002) reported an estimate for the C efflux in surface waters of the central Amazon Basin of approximately 830 ± 240 g C m^{-2} y^{-1}. Efflux values derived from this model ranged from 7 to 2600 g C m^{-2} y^{-1}, bracketing Richey et al's estimate for the Basin on average.

While this is a promising result, future work needs to be done to improve the model's representations of C cycling processes, to collect more measurements for calibration & validation (especially estimates of C supply from terrestrial environments, and submerged macrophyte productivity), and to put these processes into a spatial framework. That would allow us to calculate basin-scale efflux, including inter-annual variability, under various climate and land-use scenarios.

We hope this simple approach will complement more mechanistic approaches to modelling regional-to-basin scale carbon cycling, and will help to integrate and synthesize data from several different scales of LBA field studies.

7. References

JM Melack, BR Forsberg. 2001. Biogeochemistry of Amazon floodplain lakes and associated wetlands. Ch. 14 in ME McClain, RL Victoria, JE Richey, eds: The Biogeochemistry of the Amazon Basin. Oxford Univ Press: Oxford

N Patel, S Mounier, JL Guyot, C Benamou, JY Benaim. 1999. Fluxes of dissolved and colloidal organic carbon, along the Purus and Amazonas rivers (Brazil). The Science of the Total Environment 229:53-64.

JE Richey, et al. CAMREX dataset. Pre-LBA Initiative CD-ROM Data Sets, Disc 3.

JE Richey, JM Melack, AK Aufdenkampe, VM Ballester, LL Hess. 2002. Outgassing from Amazonian rivers and wetlands as a large tropical source of atmospheric CO2. Nature 416:617-620.

RL Victoria, JE Richey, M Bernardes, MVR Ballester, BM Gomes, AV Krusche, E Mayorga. 2000. Effects of land use changes in the biogeochemistry of Ji-Paraná river, a meso-scale river in the state of Rondonia, southern Amazon. LBA First Scientific Conference, Proceedings. Belém, Pará, Brazil. Accessed on Beija-Flor.