Project 1 (WP1-WP3-WP4): Modeling inland water greenhouse gas fluxes

Project lead: Philippe Ciais
Post-doctoral researcher: Ronny Lauerwald
Project start/end: July 2013 – June 2015

Position offer: The excellence laboratory L-IPSL of the Institut Pierre-Simon Laplace offers a post-doctoral position of 2 years to integrate into the IPSL Earth System Model some of the key previously neglected inland aquatic processes than form the so called "boundless carbon cycle". The proposed post-doctoral position project is a reaction to the growing awareness that inland waters contribute significantly to global greenhouse gas (GHG) fluxes, and to the realization that their sensitivity to projected climate change and eco-hydrological disturbance is poorly constrained.

Context : The conventional wisdom is that inland waters simply transport terrigenous organic carbon to the oceans. This view is perpetuated by current models of the global carbon cycle that largely ignore inland waters as represented in, for instance, the Intergovernmental Panel for Climate Change (IPCC) – Fourth Assessment Report (FAR), or the Integrated Global Observing Strategy report (GEO-Carbon). In the five years since the publication of IPCC's FAR in 2007, it has become apparent that the global flux of GHGs from inland aquatic sources to the atmosphere is much larger than previously suspected (Battin et al., 2008; 2009; Butman and Raymond, 2011; Bastviken et al., 2011; Barros et al., 2011). Thus, recently published estimates indicate that inland waters degas from 0.8 Pg (1Pg= 109 metric tons) of carbon per year (excluding wetlands, Cole et al. 2007), up to 3.3 Pg C y-1 (including wetlands, Tranvik et al., 2009; Battin et al., 2008; 2009; Aufdenkampe et al., 2011; Butman and Raymond, 2011), the latter estimate of similar magnitude to the terrestrial carbon sink of 2.8 Pg C y-1 (Canadell et al. 2008). Only recently have regional scale carbon balances begun to consider these fluxes (e.g. Luyssaert et al., 2012), but large knowledge gaps remain concerning their magnitude and their ultimate significance for global carbon cycle models. Current estimates based on global surveys and 'bottom up' extrapolations from streams and rivers in the United States for example indicate that this GHG flux is significant relative to the total anthropogenic flux of carbon to the atmosphere, with emissions from the northern hemisphere temperate zone (25oN-50oN) rivers alone estimated to be c. 0.5 Pg annually (Butman and Raymond, 2011). Additionally, a recent survey of CH_4 emissions from inland aquatic systems (lakes, reservoirs and rivers) indicated annual CO_2-equivalent methane emissions of a similar magnitude (0.65 Pg of C as CO_2 equivalent; Bastviken et al., 2011). These recent estimates necessitate a paradigm shift from the traditional depiction of streams, rivers and other inland freshwater bodies as inert conduits and reservoirs, to one in which the kinetics of climate-sensitive GHG production by aquatic biogeochemical transformation reactions, hydrologically driven soil gas flushing from riparian zones and the dynamics of gas transfer processes at water/air interfaces are incorporated into realistic 'boundless carbon cycle' models.

Despite the potential importance of these GHG emissions, their inclusion, even under a simplified form, in current Earth System Models is still missing, although several research teams began to work in that direction. The sensitivity of lateral C fluxes in aquatic systems to global change and eco-hydrological disturbances is largely unknown, and their overall significance for Earth's global carbon budget remains to be established as well. Much previous work on regional scale carbon balances has focused on terrestrial sinks and sources, but it is increasingly appreciated that flux measurement techniques that are applied widely to terrestrial systems (e.g. Eddy covariance methods) are inappropriate or require re-evaluation for aquatic systems.

Description of work: The postdoctoral fellow will interact with researchers at LSCE and SISYPHE laboratories, part of L-IPSL, and incorporate a set of simplified parameterizations on the land surface scheme ORCHIDEE of the IPSL Earth System model the following processes : C emissions from soils to rivers headstreams for DIC and DOC, with a highly parametric inclusion of chemical alteration fluxes of C from atmospheric origin, CO2 evasion data from rivers and floodplains, C burial in lakes and freshwater sediments and CO2 emissions from estuaries (the later using the global upscaling model developped by Pierre Regnier at University of Utrecht). The ORCHIDEE model enabled for carbon transport from soil to rivers and lakes will be tested and calibrated against a new pCO2 global database and river fluxes of DOC, DIC (COSCAT database of 150 catchments; http://www.agu.org/pubs/crossref/2006/2005GB002540.shtml). The model will be applied in the second year for characterising the presently unknown atmospheric feedbacks (positive and negative) between inland aquatic carbon evasion fluxes and drivers such as climate change and anthropogenic eco-hydrological disturbance.

Supervision team: The researcher with a PhD in earth system science, will be hired by CNRS and will be hosted at LSCE in Saclay while working in close collaboration with SISYPHE in Paris. The work will be in a project team led by Philippe Ciais, including also Laurent Bopp, Josette Garnier, Sebastiaan Luyssaert and Christophe Rabouille.

Duration and salary: The post-doctorate will be recruited for 24 months with a net monthly salary around 2000 euros, commensurate with experience. This includes social services and health insurance.

Contact for applications: Applications should include a vita, a statement of research interests and the names of at least two references including e-mail addresses and telephone numbers. Applications should be submitted by e-mail to Philippe Ciais (philippe.ciais@lsce.ipsl.fr).

Results:

(1) Step 1: A better estimate of CO2 evasion from inland waters (Lauerwald et al. 2015[1])

R. Lauerwald and co-workers[1] have established a new and more robust estimate of CO_2 fluxes between inland waters and the atmosphere at planetary scales. For that, they have used data of riverine CO_2 partial pressures (pCO_2) from ~1200 sampling locations as well as empirical prediction function for river pCO_2. They have applied this prediction equation to calculate a highly resolved (0.5°) global river pCO_2 map. Combining this pCO_2 map with spatially explicit estimates on stream surface area and gas exchange velocity, they have calculated a map of CO_2 evasion (Figure 1).

At the global scale, as representative for the time after 1990, they estimate an average river pCO_2 of 2400 µatm and a total FCO_2 of 650 Tg C yr^{-1}. About half of the global FCO_2 is contributed from the latitudinal band between 10°N and 10°S. This estimate of global FCO_2 is substantially lower than the 1800 Tg C yr^{-1} recently estimated by *Raymond et al.* [2013], mainly due to a more conservative estimate of average river pCO_2 in tropical rivers.

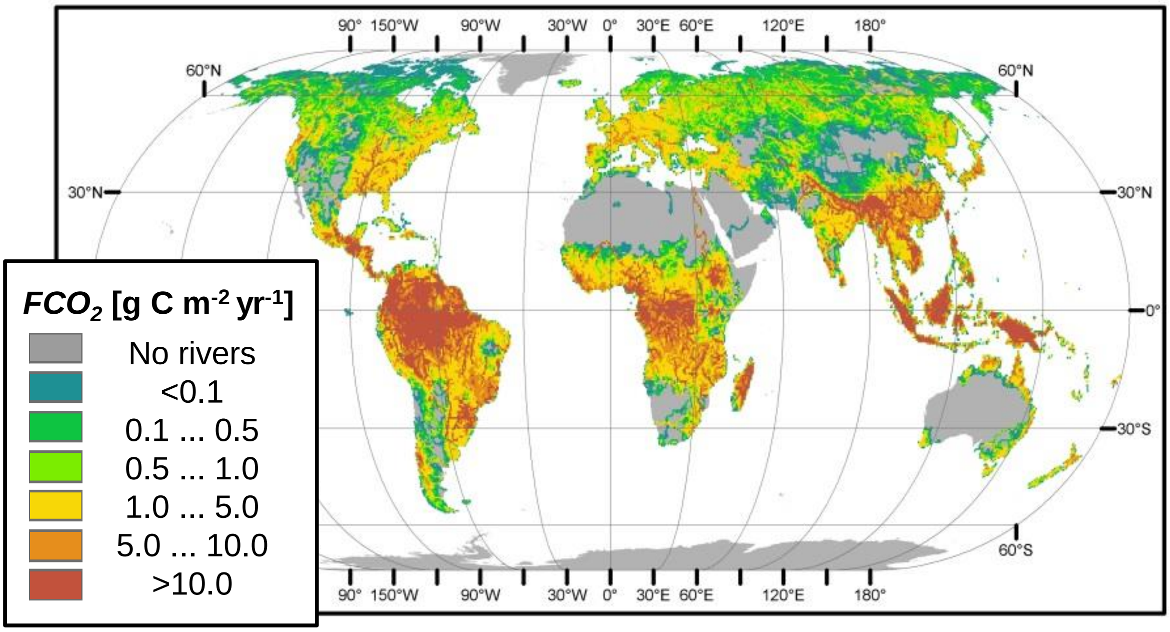

Figure 1: Estimated CO_2 evasion (FCO_2, gC $m^{-2}yr^{-1}$) per half degree grid cell[1]. FCO_2 refers to total cell area.

Step (2): Incorporation of carbon in the routine scheme of ORCHIDEE

Ronny Lauerwald has enabled the routing code of ORCHIDEE to simulate reactive lateral transport of dissolved organic carbon (DOC) and dissolved CO_2 through the inland water network. Coupled to the soil C module developed at the IPSL-LSCE (Guenet et al., in prep), this new branch of ORCHIDEE simulates the transport of DOC and CO_2 from the soil column through the river downstream to the coast, including the decomposition of DOC in transit, the evasion of CO_2 from the water surface to the atmosphere, and the exchange of dissolved C between the water column and the flooded soils in floodplains and swamps.

The new branch of ORCHIDEE was calibrated and validated using observed data from the Amazon River system. This work evidenced that the simulation of throughfall and the associated, important flux of DOC from the atmosphere and the forest canopy to soil surface and surface runoff (Figure 2) is necessary to reproduce riverine DOC fluxes (Figure 3).

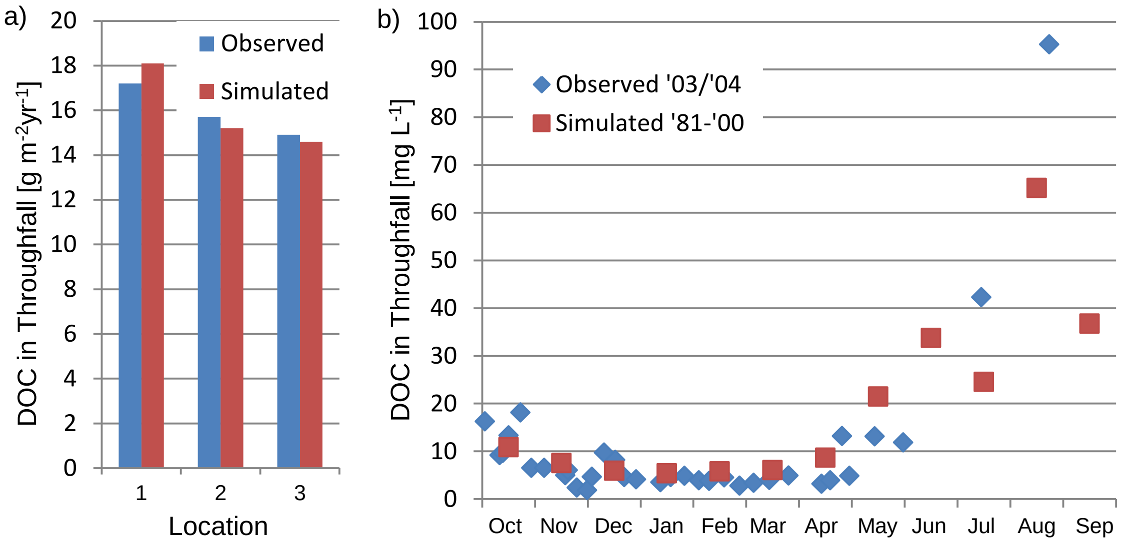

Figure 2: Observed vs. simulated values of DOC concentration and flux with throughfall in Amazonia. Panel a: Simulated annual DOC deposition related to throughfall: 1) NW Amazonia (sampling '95-'97, average of 4 sites)[2], 2) Lower Rio Negro (sampling Mar-Dec '91)[3], 3) S Amazonia (sampling '03/'04)[4]. Panel b: Seasonality in throughfall DOC concentrations at site 3, S Amazonia. Simulated monthly average concentrations ('81-'00) vs. weekly to bi-weekly observations from Oct '03 to Sep '04[4]. Note that the forcing data used here[5] cover only the period 1980-2000. While the simulations for locations 1 and 2 (panel a) could be done for the sampling period, we had to compare the annual flux and seasonality in concentrations at location 3 to the 20 year averages.

The simulation results (Fig. 3 and [6]) confirm major findings for the Amazon River system from the literature: the seasonality of CO_2 partial pressures (pCO_2) and riverine CO_2 evasion are directly related to the hydrology (varying contribution of surface runoff and deep drainage to stream flow, extend of flooded, riparian area)[7,8], the concentration of DOC in throughfall are controlled by the amount of throughfall and the duration of the preceding dry period[2], CO_2 evasion from the river water surface exceeds lateral downstream exports[7] (Fig. 3d). A surprising result is the important contribution of throughfall to the riverine DOC loads, which is not discussed in studies of river C transport at subcontinental to global scale, though being a major issue in studies of C and nutrient cycling within forest ecosystems[2–4,9].

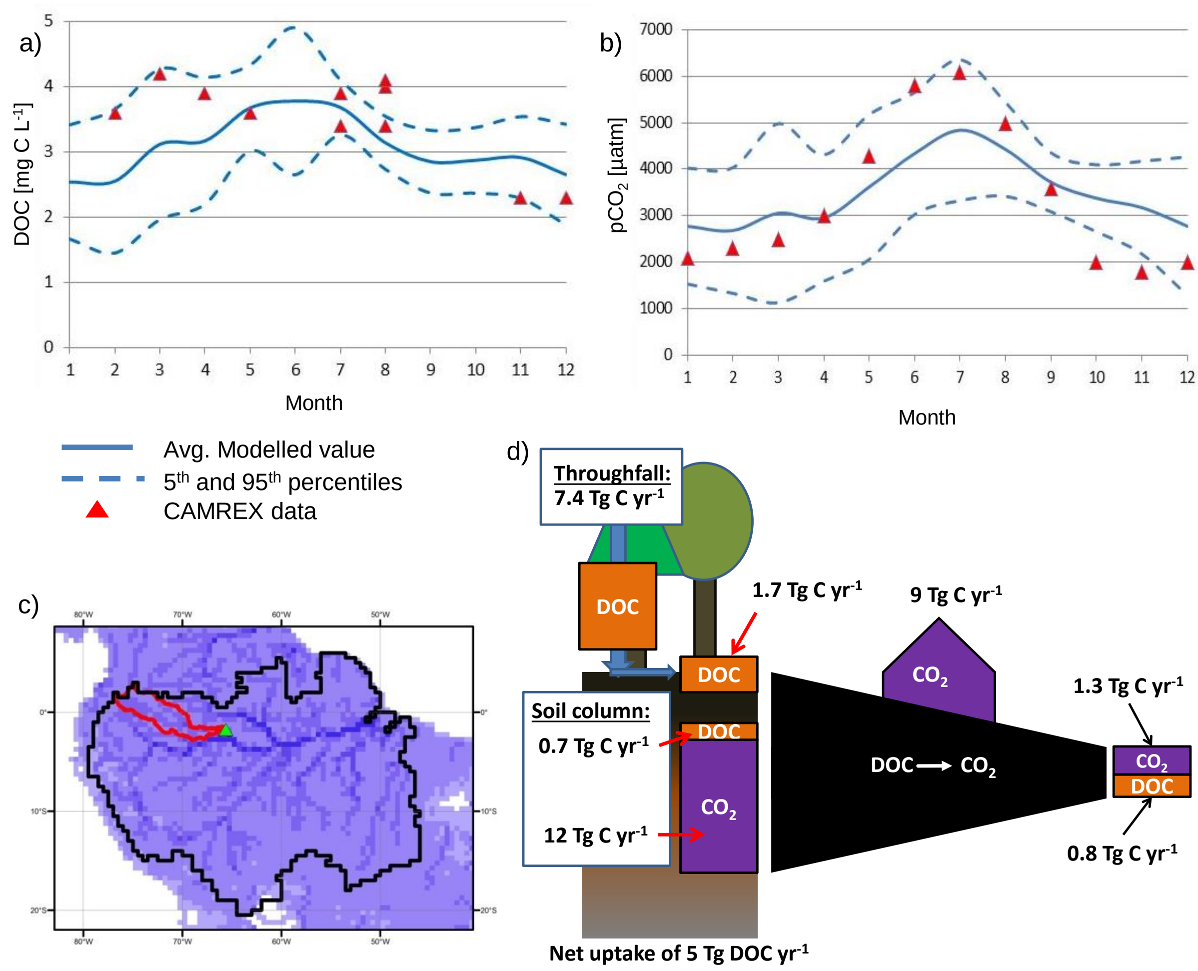

Figure 3: Simulation results for the Rio Japura Basin. Validation of simulated, average monthly a) DOC concentrations and b) pCO_2 against observation data from the CAMREX project[7,8]. Panel c) gives the location of the Rio Japura Basin within the Amazon Basin. Panel d) summarizes the simulation results of annual average DOC and CO_2 fluxes through the Rio Japura Basin; the black trapezoid represent the biogeochemical reactive inland water system which exports only a part of the C further downstream while another part is evading as CO_2 to the atmosphere.

Outlook

While the model is basically working, some minor refinements and recalibrations still have to be performed for the application to the whole Amazon basin (Lauerwald et al. in prep.). Ronny Lauerwald has obtained a 1 year fellowship from the Université Libre de Bruxelles to finalize that work with his colleagues from the IPSL-LSCE.

The regional to global scale applicability of the new ORCHIDEE branch mainly depends on performance of river flow and inundation simulations. The model was calibrated and validated for the Amazon Basin, because here, the river flow simulation performs well due to considerate efforts made to optimize regional forcing data[5].

In addition, the model depends on the performance of the soil C module. Though the soil C module was mainly calibrated for the temperate region (Guenet et al., in prep.), this work shows that, in combination with the simulation of throughfall DOC fluxes, the soil C module reproduces soil DOC exports to the river network for tropical rain forests as well.

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