Simulating the spatio-temporal variability in terrestrial - aquatic DOC transfers across Europe

Céline Gommet[1], Ronny Lauerwald[1,2], Philippe Ciais[2] and Pierre Regnier[1]

[1] Biogeochemistry and Modelling of the Earth System, Université Libre de Bruxelles, Campus Solbosch – CP 160/02,1050 Bruxelles, Belgium.
[2] Laboratoire des Sciences du Climat et de l'Environnement, IPSL/LSCE CEA-CNRS-UVSQ, Gif sur Yvette, France

Context

CO2 emissions to the atmosphere from rivers and lakes across Europe have been shown to be an important component of the continental-scale carbon budget (*Ciais et al.,2008*). An important source of CO_2 outgassed by rivers and lakes stems from the decomposition of dissolved (DOC) and particulate organic carbon (POC) lost by soils to aquatic systems. These transfers and transformations of organic carbon decrease the amount of CO_2 sequestered in soil carbon stocks and, therefore, the land carbon sink of anthropogenic CO_2 emissions could be significantly smaller than previously thought. The first step is to quantify the carbon that is exported from the land to the LOAC (land ocean aquatic continuum) system. Observational data alone cannot resolve the complex spatiotemporal variability in DOC leaching at the European scale. Furthermore, our aim is also to understand temporal trends in DOC leaching in response to climate change, LUC. For this purpose, we apply ORCHILEAK, a land surface model that represents fluvial processes explicitly (see Method section).

Objectives

Assess and project DOC leaching fluxes at the European scale.
Understand the spatio-temporal variability of DOC leaching and investigate its dominant drivers : Runoff, Drainage, Temperature & Precipitation

Method

ORCHIDEE (Organizing Carbon and Hydrology in Dynamic Ecosystems) (Krinner et al., 2005) is a land surface model that simulates the C dynamics of vegetation and soils, including its dependence on energy and water fluxes and plant phenology, and its response to rising atmospheric CO2 concentrations, changing climate, and land use change.
ORCHILEAK is a new branch of ORCHIDEE (Lauerwald et al., 2017). It simulates DOC cycling and fluxes in the soils, from soils to inland waters, and the non-conservative transport of DOC in the river network. It thus simulates the lateral leaching of DOC from soils to aquatic systems, a component usually neglected in the soil C budget.

ORCHILEAK has been used to model specific regions in the tropics (Lauerwald et al. 2017; Hastie et al., 2020) and in the Arctic (Bowring et al., 2020). Here, for the European region, we need to adapt the model and the forcing's data sets. We developed a new soil carbon module to better represent the DOC concentrations in the soil based on Parton et al., 1988 and Camino-Serrano et al., 2018 (figure2). DOC dynamics is controlled by the conservation equation.

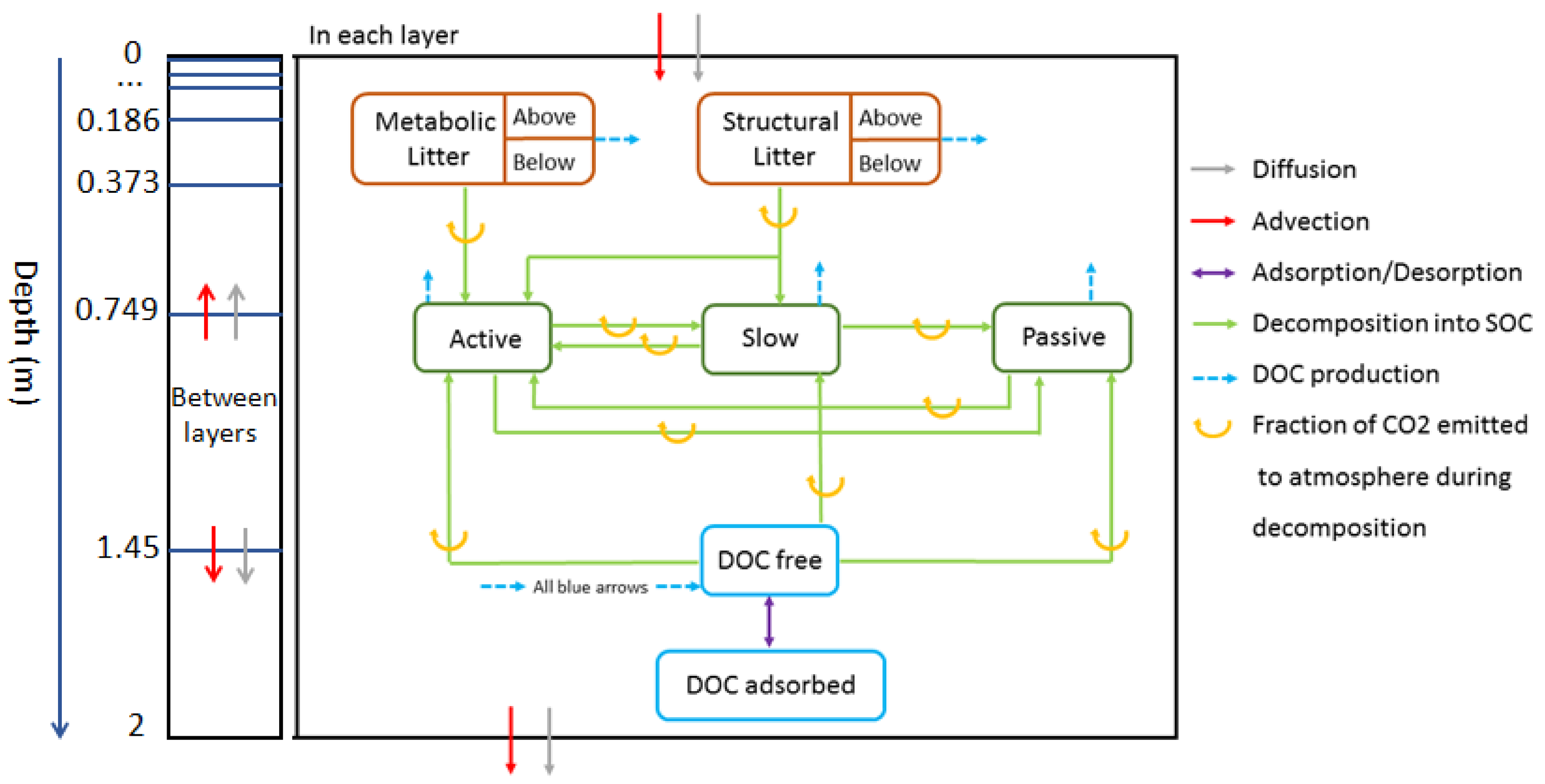

Figure 2. New soil carbon module. Right box represents what occurs in each layer.

For the forcings, the configuration from Lauerwald et al. 2017 is used except for the atmospheric data set where we used WFDEI at 0.5° resolution and the land cover from Peng et al., 2017 which partition the land surface in 13 pft's (plant functional types).

Simulations:
After reaching steady-state for all C pools including soil C (SOC) stocks, model results were evaluated against discharge at 11 gauging stations (GRDC) for hydrology, against CARDAMOM(Bloom et al., 2015) and GIMMS for NPP, and against HSWD for SOC stocks. In addition, the soil DOC depth distribution was evaluated at three sites (Carlow, Brasschaat and Hainich, those observations are scarce and rare in EU) while DOC concentration and fluxes where compared to observations (GLORICH Hartmann et al., 2014) in the river basins of the Rhine, Elbe, Seine and Rhone.

Conclusion

ORCHILEAK is able to reproduce the present C cycling at the terrestrial-aquatic system's interface
The DOC leaching reveals strong spatial and temporal variability. The key driver of the spatial variability is runoff, drainage and temperature having a weaker influence.
The next step is to project changes in DOC leaching across Europe for the 21st century.

Results

- We first evaluated the discharge in term of absolute discharge and seasonality (shown in the Rhone at Beaucaire as an example, Fig.3). We used the NSE (Nash Sutcliffe modeling efficiency coefficient and R2 to evaluate the hydrology at all stations in the 4 basins, with magnitude generally overestimated and seasonality generally well represented.
- Modelled NPP for the EU at 432 gC/m².yr falls within the error range of both datasets (GIMMs: 430 gC/m².yr; CARDAMOM 452 gC/m².yr).
- The total SOC stock is estimated at ~70 TgC for the EU. Comparing the distribution of DOC in the soil at the three sites show similar patterns although the model generally overestimates DOC concentrations in the first 10 cm (by max. a factor of 2)
- River DOC concentrations in are generally underestimated but DOC fluxes generally show satisfactory NSE and R^2 because discharge and DOC concentrations counterbalance each other.

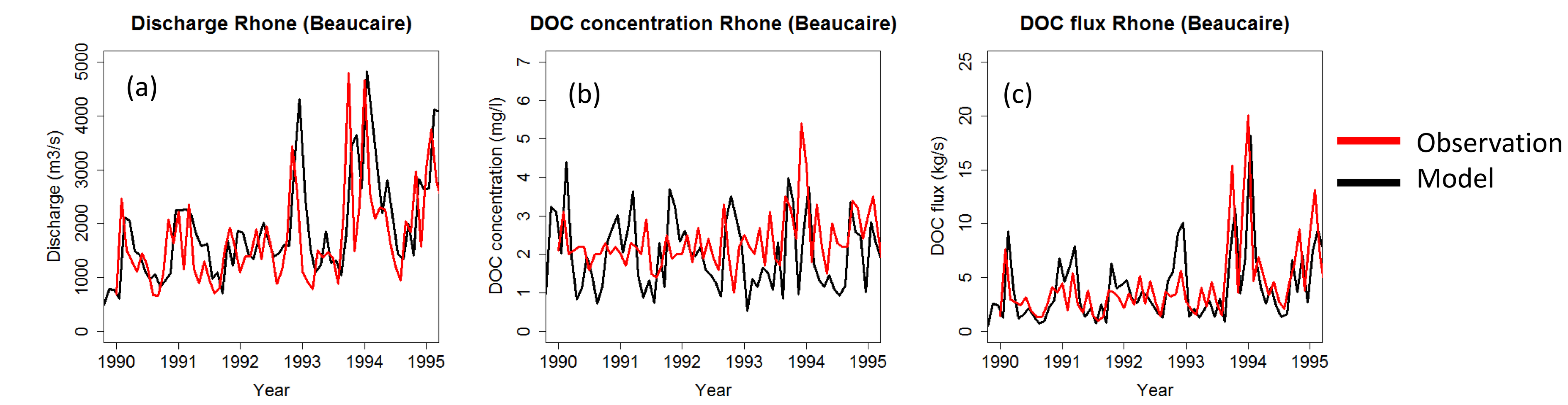

Figure 3. Evaluation for the Rhone. (a) Discharge in m³/s. (b) DOC concentration in mg/L (c) DOC flux in kg/s.

Fig 4(a) presents the present-day spatial distribution of DOC leaching and its seasonality by presenting the average for three months. On yearly average, the EU, 7,8 TgC of DOC are leached into the river network with a strong spatial variability. Throughout the year, a strong seasonality is observed, with generally minimum leaching during summer and maximum leaching during winter and to a lesser, extent autumn. Regions subject to snow melt like Finno-Scandinavia and the Alps reveal maximum DOC leaching in spring.

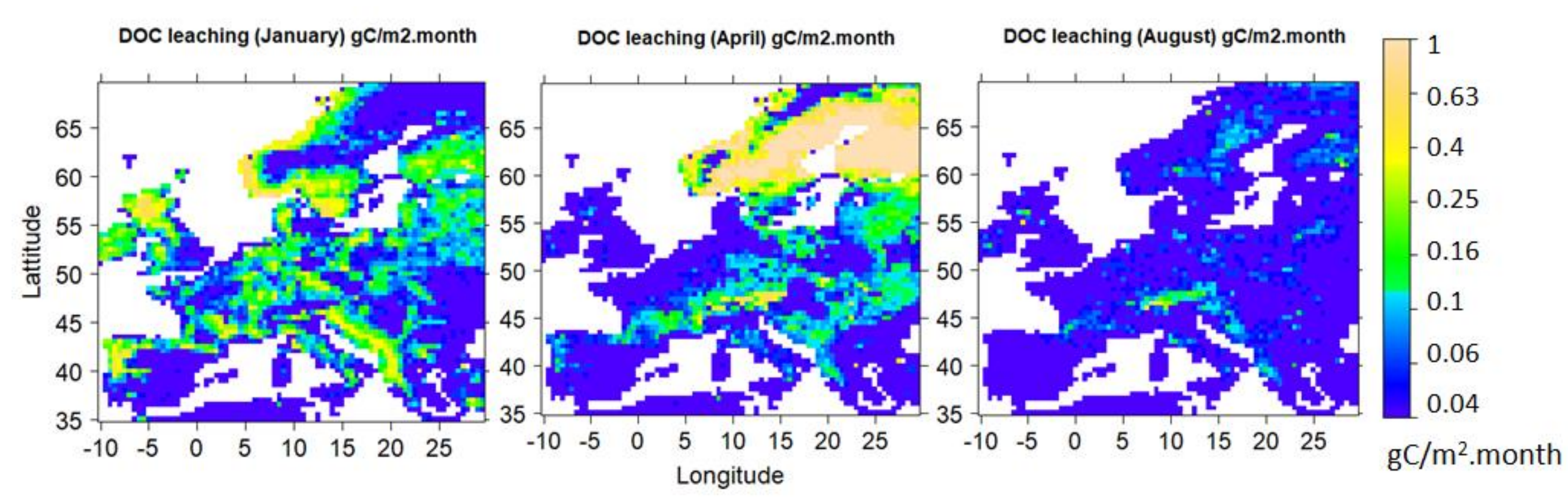

Figure 4. DOC leaching along the year, monthly average DOC leaching in gC/m2.month for the present-day period.

We investigated some driver variables to understand what controls the DOC leaching. Our results suggest that the temperature (T) and precipitation (and thus, runoff (R) and drainage (D)) have a strong influence. (Semi-arid climate present the lowest fraction of NPP leached into LOAC (dry and warm) while tundra & subarctic climates show highest normalized fluxes (cold). Another important factor could be the snow melt leading to high runoff in spring. Total runoff and temperature could thus be important drivers, which are considered independent (R2 of 0.1). Fig5(a) shows the fraction of NPP that is leached as DOC in the river network (yearly average) and fig5(b) represents for each grid cell of the European domain the DOC leaching normalized by the NPP as a function of the total runoff and temperature. Based on those results, we established a predictive equation for the fraction of NPP leached as DOC (Fig 5c):

$$\frac{DOC\ leaching}{NPP} = K_0 + K_R * R + K_D * D + K_T * e^{T(°C)}$$

Where K_0=2*10^{-2} ; K_R=2,4*10^{-4}; K_D=9,5*10^{-6}; K_T=-1,7*10^{-10}
Mean error = -0.0028 and R^2 = 0.97.

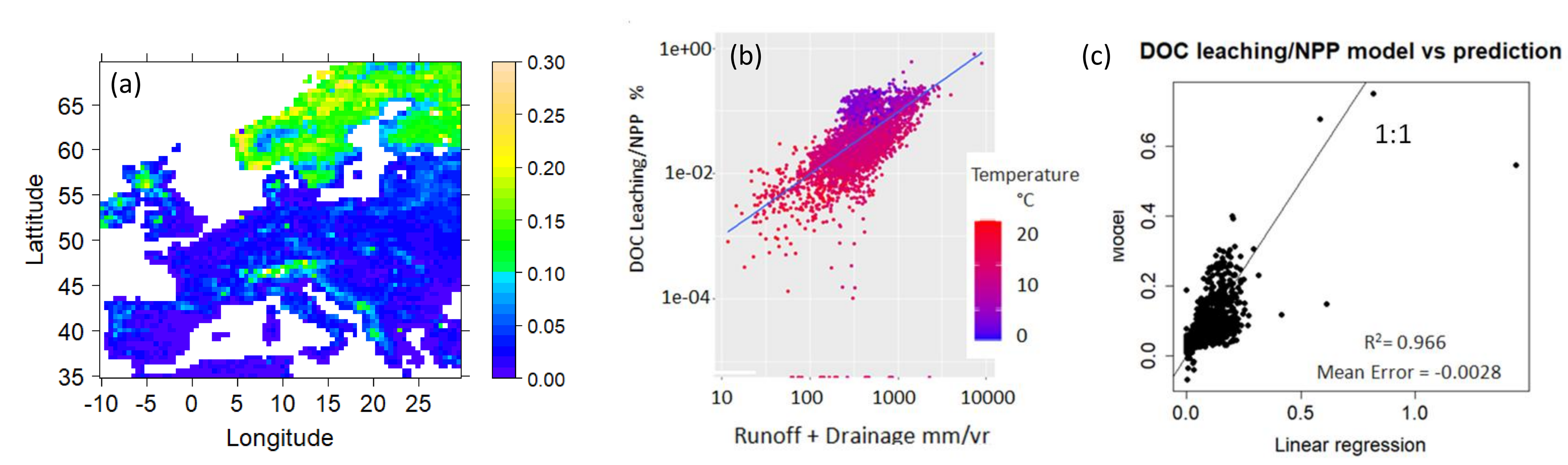

Figure 5. (a) DOC leaching normalized by the NPP, yearly average (%) (b)DOC leaching normalized by the NPP as a function of runoff+ drainage and temperature. Trend line displayed. (c) Model versus prediction with 1:1 line

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